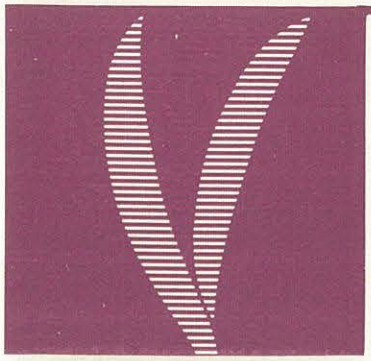
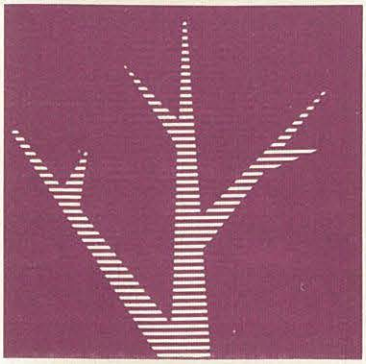
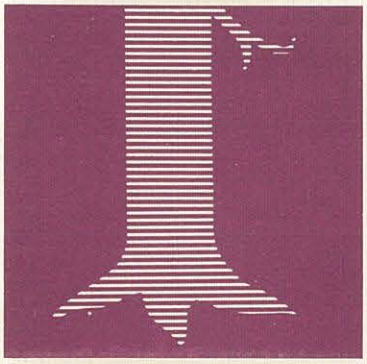
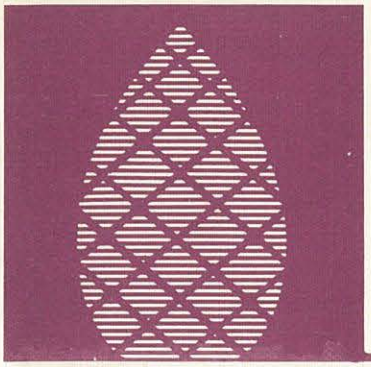
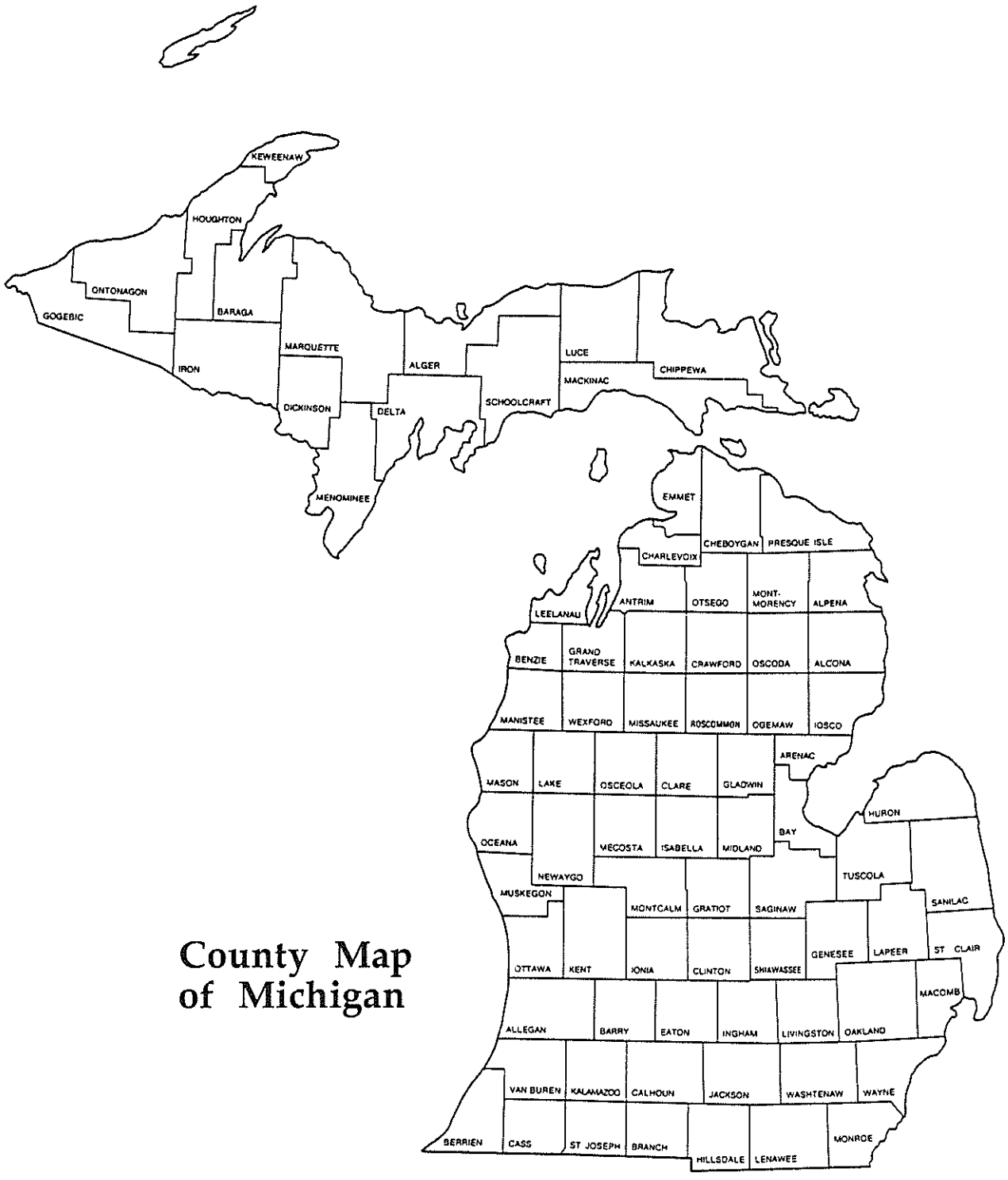








MICHIGAN FOREST PEST REPORT 1987



County Map of Michigan

Cover Design by Tina Stojakovich, Michgan DNR

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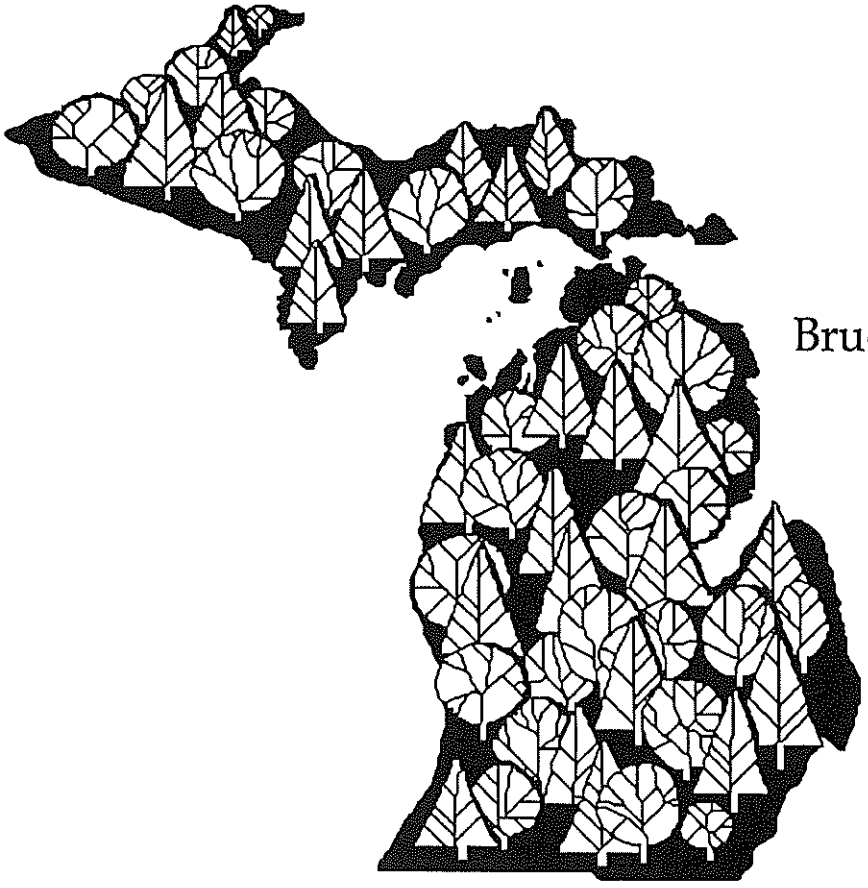

Michigan Cooperative Forest Pest Management Program Annual Report 88 - 2

Bruce A. Montgomery (Editor)

April 1988

PREFACE
Michigan Forest Pest Report: 1987

COOPERATIVE FOREST PEST MANAGEMENT PROGRAM

The Michigan Cooperative Forest Pest Management Program is firmly dedicated to helping fulfill forest management objectives by providing forest land managers with practical pest management information to improve decision making. In existence since the mid 1970s, the Program brings together expertise from seven cooperating organizations.

Member institutions of the Michigan Cooperative Forest Pest Management Program include:

Michigan Department of Agriculture
Michigan Department of Natural Resources
Michigan State University
Michigan Technological University
University of Michigan
USDA Forest Service NCFES and S&PF
Michigan Forest Industry

Directors of the Michigan Cooperative Forest Pest Management Program are:

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LOUIS WILSON (USDA Forest Service)
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PURPOSE OF THE MICHIGAN FOREST PEST REPORT

The *Michigan Forest Pest Report: 1987* is the Forest Pest Management Program's eighth annual cooperative report. It is one way that the Cooperative Program disseminates pest management information to forest land managers. This Report summarizes pest related information from one year -- 1987. Contributors to the report include forest pest specialists from universities, government agencies, and extension. The time that they take to inform the Michigan forest land manager about the status of forest pests and results from research and development projects helps all of us keep abreast of Michigan's forest pest situation and pest management issues and concepts.

TO OBTAIN COPIES OF THE MICHIGAN FOREST PEST REPORT

Copies of the *Michigan Forest Pest Report: 1987* are available from:

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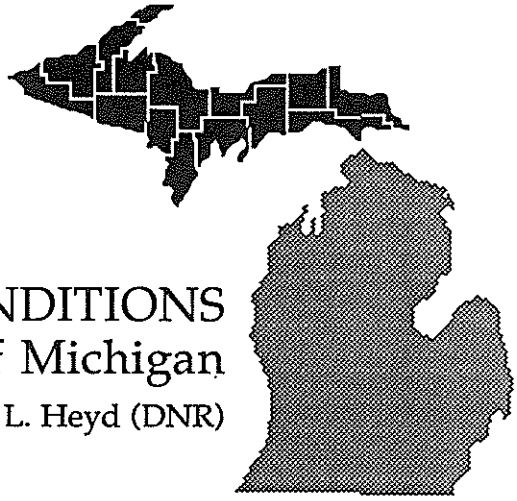


1987 PEST CONDITIONS
The Upper Peninsula of Michigan

Robert L. Heyd (DNR)

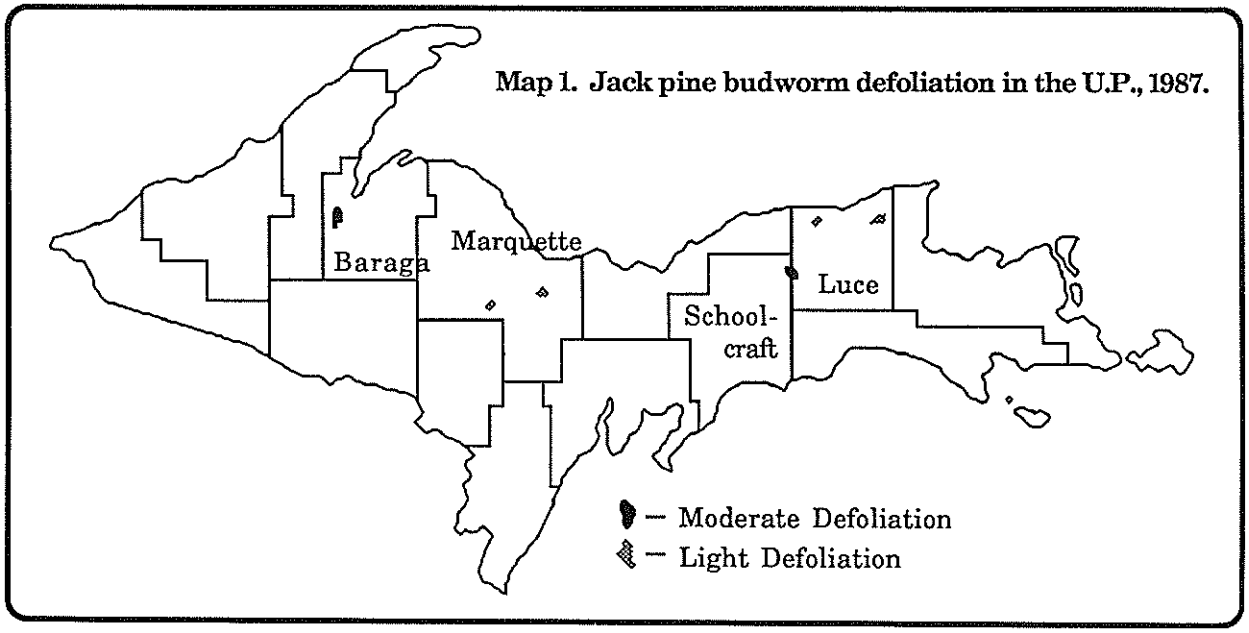
JACK PINE BUDWORM

(*Choristoneura pinus*)

Jack pine budworm populations are building in many areas of the Upper Peninsula. Light defoliation was noticeable in many jack pine areas. The Baraga Plains in Baraga County and the jack pine type shared by Schoolcraft and Luce Counties were moderately defoliated (Map 1). This map is the result of an aerial sketch mapping survey flown in July. Some areas of light defoliation were visible from the air as shown. Many areas of light defoliation were not visible from the air and are not included in the map.

A total of 54 permanent impact plots have been established in jack pine areas across the U.P. Plots are used to monitor the effects of jack pine budworm feeding on tree growth and mortality and to develop risk rating criteria. Surveys of early instars, late instars, pupae, and adults were conducted within 16 plots (see pages 47 to 53 for a summary of population trends).

To date, the current budworm epidemic has not caused measureable impact except in Schoolcraft County from 1983 to 1985. Some top kill and scattered tree mortality were reported over 1,200 acres. Budworm populations collapsed unexpectedly throughout the U.P. in 1986. This allowed the stressed trees to retain new foliage and at least partially recover. The 1987 resurgence of budworm populations throughout the U.P. forewarns of a potentially serious epidemic over the next two to three years.



Map 1. Jack pine budworm defoliation in the U.P., 1987.

GYPSY MOTH

(*Lymantria dispar*)

The gypsy moth is a serious defoliator which favors oaks (*Quercus* sp.) and aspen (*Populus* sp.). The Lower Peninsula is generally infested and experiencing defoliation in several areas. We have not to date found any viable gypsy moth populations in the Upper Peninsula. With increases in gypsy moth populations in the northern portion of the Lower Peninsula and at the Wisconsin/U.P. (Menominee County) border, we will likely see more movement of gypsy moth egg masses, pupae, and even larvae into the U.P. on recreational vehicles, firewood, and household articles.

The Michigan Department of Agriculture (MDA), USDA Forest Service, and the Michigan Department of Natural Resources are working cooperatively to detect the movement of gypsy moth life stages into the U.P. For example, pheromone traps are baited with a lure and used to attract and capture male moths. The traps can effectively and efficiently detect the possible movement of moths into a previously moth-free area. Each trap location is now used as a permanaent monitoring site. For 1988 we expect to set four times the current number of traps in some eastern and central U.P. counties.

Seventeen moths were captured in the U.P. in 1986 while 67 moths were captured in 1987 (Table 1). However, the male moths were only detected in two counties in 1987 compared with catches in five counties in 1986.

Three traps recorded multiple moth catches. Single moth catches have occurred in previous years without subsequent establishment of the gypsy moth. The relatively large number of single catches in Chippewa and Mackinac counties, however, indicates an increased opportunity for the gypsy moth to establish.

To confirm the presence of a potentially establishing gypsy moth population, evidence of another life stage is required. The MDA remains committed to an early detection/suppression program to prevent the establishment of the gypsy moth in the U.P. If evidence of an establishing population is found, the area will be defined and sprayed in an attempt to eradicate the insect while still in the less stable establishment phase. The gypsy moth is subject to many environmental deterrents (e.g., parasites, predators, weather, and spatial separation) which can help prevent establishment. Early detection of the gypsy moth is essential to optimize the outcome of a spray program. It must capitalize on environmental deterrents and extremely low population numbers.

Table 1. Results of the 1986 and 1987 gypsy moth trapping surveys in U.P. counties where moths were detected.

	1986		1987	
County	Total number of moths	% positive traps	Total number of moths	% positive traps
Chippewa	2	2	54	27
Delta	2	4	0	0
Luce	4	10	0	0
Mackinac	8	15	13	18
Menominee	1	2	0	0
Total	17		67	

ORANGE-HUMPED MAPLEWORM

(*Symmerista leucitys*)

The eastern Upper Peninsula once again experienced a significant orange-humped mapleworm outbreak. The mapleworm defoliated 730 acres of sugar maple in the McNearney Lake area of Chippewa County. This general area of Chippewa County has had as many as 7,000 acres of sugar maple forest defoliated in a single year (Table 2).

We expected little or no defoliation in 1987. We again expect the mapleworm to continue declining in 1988 with a good chance for a complete population collapse.

The orange-humped mapleworm begins feeding in mid to late August. This late season defoliator has a negligible effect on tree growth and vigor. Although residents and visitors in the area find the presence of the insect and the loss of leaves very undesirable, no control measures were taken.

Table 2. Defoliation by the orange-humped mapleworm in the U.P.

Year	Defoliation	Acres
1985	Light	240
	Moderate	1,360
	Heavy	5,340
1986	Mod/Heavy	2,420
1987	Heavy	730

REDHEADED PINE SAWFLY

(*Neodiprion lecontei*)

Redheaded pine sawfly population levels were much diminished compared to levels in 1985 and 1986. Small pockets of defoliation were found in Luce, Mackinac, and Chippewa counties.

EASTERN TENT CATERPILLAR

(*Malacosoma americanum*)

The eastern tent caterpilar was extremely abundant in 1987 as evidenced by numerous webbed tents in cherry and apple trees during the spring. These tents were highly visible along roadways throughout the Upper Peninsula.

Late-instar caterpillars spend the daylight hours in the tents. They emerge after dark to feed on tree leaves. Although all leaves may be eaten, the tree usually survives. A new set of leaves is produced within a month or so.

YELLOWHEADED SPRUCE SAWFLY

(*Pikonema alaskensis*)

Ornamental and plantation white spruce, *Picea glauca*, in the north central Upper Peninsula were heavily defoliated by the yellowheaded spruce sawfly in 1987. We received numerous calls from concerned landowners in Baraga, Houghton, Keweenaw, and Ontonagon counties.

The sawfly larvae defoliated trees in June causing top-kill and mortality of heavily defoliated trees. Small trees are most susceptible to severe defoliation. Trees taller than 20 feet are usually less susceptible to complete defoliation, but the top few whorls of branches may be completely stripped of foliage. Chemical control is often necessary to protect trees.

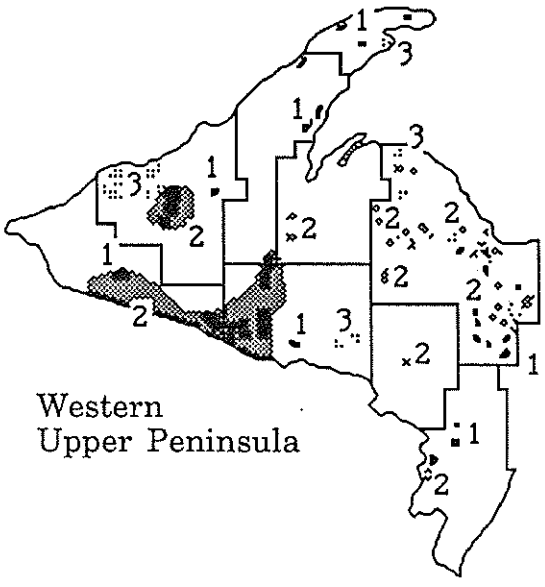
HARDWOOD DEFOLIATORS:

BRUCE SPANWORM (*Operoptera bruceata*)
FALL CANKERWORM (*Alsophila pometraria*)
LINDEN LOOPER (*Erannis tillaria*)
FOREST TENT CATERPILLAR (*Malacosma disstria*)

The Bruce spanworm, fall cankerworm, linden looper, and forest tent caterpillar, alone or in some combination, defoliated hardwood stands in many areas of the U.P. (Table 3 and Maps 2 and 3). The degree of leaf loss varied greatly between areas. Maps 2 and 3 do not depict all areas of hardwood defoliation but do show the larger, distinct areas which were detected during ground or aerial surveillance. Table 3 reports mapped acreages. Many of our hardwood forests in the U.P. seemed to be experiencing at least light defoliation.

Sugar maple (*Acer saccharum*), beech (*Fagus grandifolia*), yellow birch (*Betula alleghaniensis*), and basswood (*Tilia americana*) were the tree species most frequently defoliated by the Bruce spanworm, fall cankerworm, and linden looper. Northern red oak (*Quercus rubra*) and aspen (*Populus tremuloides*) forests were more commonly attacked by the forest tent caterpillar. The largest areas of forest tent caterpillar defoliation were observed near Ontonagon, Marquette, and Sault Ste. Marie.

Temporary observation plots were established in defoliated hardwood areas to monitor foliage reflush and any adverse impacts. Heavily defoliated areas reflushed by early July as expected. 1987 was the second consecutive year of widespread defoliation by these insects. Some portions of the southwestern U.P. (east Iron County) have been defoliated for three to four years. To date, this early season defoliation has not resulted in measurable impact.



Hardwood Defoliation Levels

1: Severe Defoliation

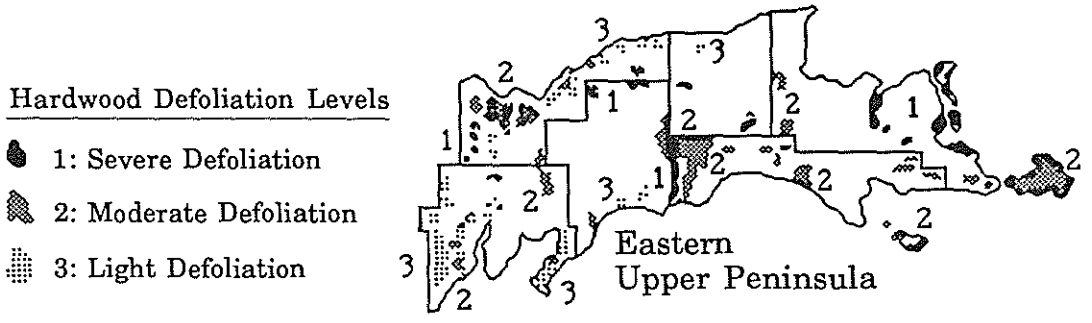
2: Moderate Defoliation

3: Light Defoliation

Map 2. Hardwod defoliation in the western U.P., 1987.

Table 3. Acreage of hardwood defoliation in the U.P. by county, 1987.

County	Defoliation			Total
	Light	Moderate	Heavy	
Alger	1,700	3,840	5,860	11,400
Baraga	0	640	0	640
Chippewa	5,760	100,000	60,000	165,760
Dickinson	640	0	0	640
Delta	20,480	7,040	0	27,520
Houghton	0	2,560	0	2,560
Iron (east)	1,280	0	160	1,440
Keweenaw	0	800	0	800
Luce	5,120	1,280	640	7,040
Mackinac	40,040	13,720	12,160	65,920
Marquette	3,040	6,400	3,200	12,640
Menominee	0	1,320	1,000	2,320
Ontonagon	5,120	0	0	5,120
Schoolcraft	5,000	3,360	1,920	10,280
Totals	88,180	140,960	84,940	314,080



Map 3. Hardwood defoliation in the eastern U.P., 1987.

MINOR PEST PROBLEMS IN THE UPPER PENINSULA - 1987

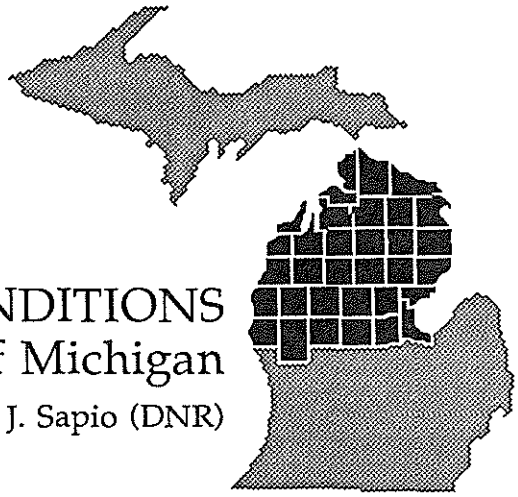
PEST	HOST(S)	COUNTY	REMARKS
Aphids	Jack pine, Scots pine	Upper Peninsula	Commonly present in young jack pine stands before crown closure. Occasional heavy populations causing wilt symptoms.
Aspen blotch minor *(Lithocolletis tremuloidiella)*	Quaking aspen	Upper Peninsula	Damage noticeable, but not heavy in most areas.
Armillaria root rot *(Armillaria mellea)*	Jack pine	Upper Peninsula	Scattered single tree mortality in young pine plantations.
Bark beetles *(Ips pini)*	Jack pine	Baraga County	Spring drought and jack pine budworm defoliation exerted stress on trees. Small pockets of scattered tree mortality in June and July. Wet summer ameliorated problem.
Birch leafminer *(Fenusa pusilla)*	White or paper birch	Upper Peninsula	Locally heavy populations.
Birch skeletonizer *(Bucculatrix canadensisella)*	White or paper birch	Upper Peninsula	Populations low in most areas.
Bladder gall mites	Silver maple, red maple	Upper Peninsula	Occasional calls from homeowners.
Bronze birch borer *(Agrilus anxius)*	White or paper birch	Upper Peninsula	Very few calls reporting birch decline or mortality.
Bruce spanworm *(Operophtera bruceata)*	Sugar maple, beech, other hardwoods	Upper Peninsula	Complete defoliation of hardwoods in many areas. Occurred with fall cankerworm, linden looper, and forest tent caterpillar (see report).
Eastern pine shoot borer *(Eucosma gloriola)*	Scots pine, jack pine, red pine	Upper Peninsula	Common occurrence in young pine plantations.
Fall cankerworm *(Alsophila pometaria)*	Sugar maple, other hardwoods	Upper Peninsula	Contributed to heavy defoliation of hardwoods across U.P. Associated with linden looper, Bruce spanworm, and forest tent caterpillar (see report).

PEST	HOST(S)	COUNTY	REMARKS
Forest tent caterpillar *(Malacosoma disstria)*	Quaking aspen, northern red oak	Marquette, Ontonagon counties	Areas of heavy defoliation.
Gall rusts *(Cronartium quercum)*	Jack pine, Scots pine	Upper Peninsula	Common in jack pine areas.
Hypoxylon canker *(Hypoxylon mammatum)*	Quaking aspen	Upper Peninsula	Found commonly throughout the U.P. Severely limits the growth of aspen in areas of high disease prevalence.
Large aspen tortrix *(Choristoneura conflictana)*	Quaking aspen	Upper Peninsula	Defoliation down from intensity of previous years in most areas. May be in competition with other hardwood defoliators.
Linden looper *(Erannis tiliaria)*	Maple, basswood	Upper Peninsula	Very heavy defoliation in hardwood stands across the U.P. Occurred with Bruce spanworm and fall cankerworm (see report).
Maple decline	Sugar maple, red maple	Upper Peninsula	Continuing problem in urban areas.
Maple petiole borer *(Caulocampus acericaulis)*	Sugar maple	Upper Peninsula	Few reports or observations.
Maple trumpet skeletonizer *(Epinotia aceriella)*	Sugar maple	Upper Peninsula	Few reports or observations.
Mountain-ash sawfly *(Pristiphora geniculata)*	Mountain ash	Upper Peninsula	Common problem of mountain ash wherever grown.
Oak decline	Northern red oak	Upper Peninsula	Scattered declining oak trees in some areas resulting from severe drought conditions experienced in 1983 and the spring of 1984 and 1987.

Continued on next page.

PEST	HOST(S)	COUNTY	REMARKS
Orange-humped mapleworm *(Symmerista leucitys)*	Sugar maple, beech	Chippewa County	Heavy defoliation for the fifth consecutive year in the McNearny Lake area. Defoliated acreage much smaller. Population collapse is expected in 1988.
Oak decline	Northern red oak	Upper Peninsula	Scattered declining oak trees in some areas resulting from severe drought conditions experienced in 1983 and the spring of 1984 and 1987.
Orange-humped mapleworm *(Symmerista leucitys)*	Sugar maple, beech	Chippewa County	Heavy defoliation for the fifth consecutive year in the McNearny Lake area. Defoliated acreage much smaller. Population collapse is expected in 1988.
Pine root collar weevil *(Hylobius radicus)*	Scots pine	Upper Peninsula	Limits the utility of Scots pine as an economically viable candidate for reforestation efforts in the Upper Peninsula.
Pine spittlebug *(Aphrophora parallella)*	Scots pine, white pine	Upper Peninsula	Few reports or observations.
Pitch midge *(Cecidomyia spp.)*	Jack pine	Upper Peninsula	Scattered areas with numerous flagged branchlets.
Pitch nodule maker *(Patrova albicapitana)*	Jack pine, Scots pine	Upper Peninsula	Commonly found in low numbers. Few areas with unusually high occurrence.
Red pine needle midge *(Contarinia spp.)*	Red pine, Scots pine	Delta, Iron, Dickinson, Marquette, Mackinac	No reported or observed attacks.
Redheaded pine sawfly *(Neodiprion lecontei)*	Jack pine, red pine	Luce	A small sawfly pocket was sprayed in one plantation in Luce County. Populations were down from 1986.
Scleroderris canker *(Gremmeniella abietina)*	Jack pine, red pine	Luce, Schoolcraft	Light flagging of lower whorl branches. Incidence down from 1986. Not threatening.
Tar spot needle cast *(Davisomycella*	Jack pine	Marquette	Common in several jack pine plantations south of Ishpeming.

PEST	HOST(S)	COUNTY	REMARKS
White grubs *(Phyllophaga spp.)*	Jack pine, red pine	Upper Peninsula	White grubs continue to be a problem on old field type planting sites.
White pine weevil *(Pissodes strobi)*	Jack pine, white pine	Upper Peninsula	Two jack pine plantations in Marquette with 10% weeviling.
White trunk rot of aspen *(Phellinus tremulae)*	Quaking aspen	Upper Peninsula	A large portion of our aspen resource is mature or over-mature and in need of harvesting.
Willow leaf beetle *(Plagiodera versicolora)*	*Salix* spp.	Schoolcraft	Populations dramatically down from last year. A few small areas with noticeable defoliation.
Yellow birch decline	Yellow birch	Baraga, E. Iron	Much less noticeable in 1987.



1987 PEST CONDITIONS
The Northern Lower Peninsula of Michigan

Frank J. Sapio (DNR)

ENGRAVER BEETLES

(*Ips* spp.)

Bark beetle activity should increase in 1988 due to unusually dry weather conditions and a fairly heavy increase in beetle populations in 1987. Reports originating regionwide show a significant increase in pine mortality associated with *Ips* compared to 1986. Currently, we are not experiencing severe beetle outbreaks in most areas, yet the possibility does exist. Ultimately, weather is the variable that will tip the scales. During the winter of 1987-88, our soil moisture was nearly at capacity. If this level is maintained we will probably avoid more serious bark beetle problems. If conditions become dry this spring and summer, we may be on the threshold of severe bark beetle problems in the Lower Peninsula.

Susceptibility to bark beetle attack is related to the health of the tree. Healthy trees are less susceptible to outbreaks. These trees produce chemicals which can be toxic to bark beetles and their associated pathogens. Pine trees also produce copious amounts of resin. The chemicals and the resin are natural mechanisms by which healthy trees ward off the bark beetles.

Trees that become stressed due to overcrowding or drought produce chemicals, called terpines. Logging debris and slash also produce the terpines. The chemicals attract male beetles and guide them to host trees. The male bark beetles bore through the bark to the phloem region. As the male bark beetles feed, other chemicals are released which attract females to the area. Once the females join in the attack, more chemicals are released, this time by the female to attract males to mate. Although simplified, this summary of bark beetle attack gives us some insight on how we can minimize bark beetle problems.

We can manage the bark beetle in individual stands by intervening in the infestation process. This is largely a preventative process although it is also possible to break the cycle once it has started. The folowing practices can be used to minimize bark beetle infestations:

1. Avoid harvesting or thinning pine in dry years.
2. Harvest or thin pine from September to April, if possible.
3. If harvest must occur from April to September, scatter slash so that breeding material dries and the chemical attractants volatize during non-breeding months.
4. Avoid storage of pine sawlogs and pulpwood near pine stands particularly during spring and summer.
5. Maintain stands at optimum stocking density. Stands of healthy trees do not produce large amounts of attractants necessary to start the infestation process.

Although it is too early to determine whether the Lower Peninsula is on the brink of a major bark beetle outbreak, we should start working towards minimizing potential losses through preventative management practices.

SARATOGA SPITTLEBUG ON RED PINE

(*Aphrophora saratogensis*)

Seven plantations were surveyed for Saratoga spittlebug nymphs in 1987 (Table 4). The spittlebugs were hardly detectable due in part to the very dry weather in the spring, 1987. This pest has become a minimal problem over the last few years due to sound site selection, site preparation, release from alternate hosts, and dry weather.

This year we treated approximately 70 acres of newly planted red pine with Roundup® at 2 quarts per acre. The objective of the treatment was to reduce the alternate hosts of the Saratoga spittlebug in high value plantations.

Table 4. Saratoga spittlebug populations in red pine plantations, 1987.

County	Location	Acres	Nymphs/ Tree Unit
Gladwin	18N,2E,S27 NWNENE	12	0.43
Gratiot	25N,10W,S31 SW	168	0.06
Kalkaska	27N,8W,S23 NESE	32	0.00
Lake	20N,12W,S32 NWNWSW	10	0.00
Lake	20N,12W,S32 W1/2SWNW	27	0.09
Lake	20N,13W,S25 N1/2SWSW	24	0.00

EASTERN TENT CATERPILLAR

(*Malacosoma americanum*)

Outbreaks of this pest of scrub cherry, aspen and sometimes oak resulted in more phone calls in 1987 than we care to remember. Many people view this pest as an eye-sore and a nuisance. The insect is a greater fire hazard than a pest problem as many people seem to get great joy from burning the caterpillars' nests. This is truly a problem as we have had more than one fire started in Region II from this activity.

REDHUMPED OAKWORM

(*Symerista canicosta*)

The number of acres defoliated by the redhumped oakworm in 1987 was lower than the previous year's total of 3,000 acres. Although we did not get a chance to map the defoliated area, most of the activity has occurred on oak in Manistee County. The oakworm is a significant nuisance, but does little harm to its hosts since it defoliates trees late in the season. By the time the leaves are stripped by this pest, most photosynthesis has been completed and the trees are ready to drop their leaves. We expect populations of this pest to continue to decline.

FOREST TENT CATERPILLAR

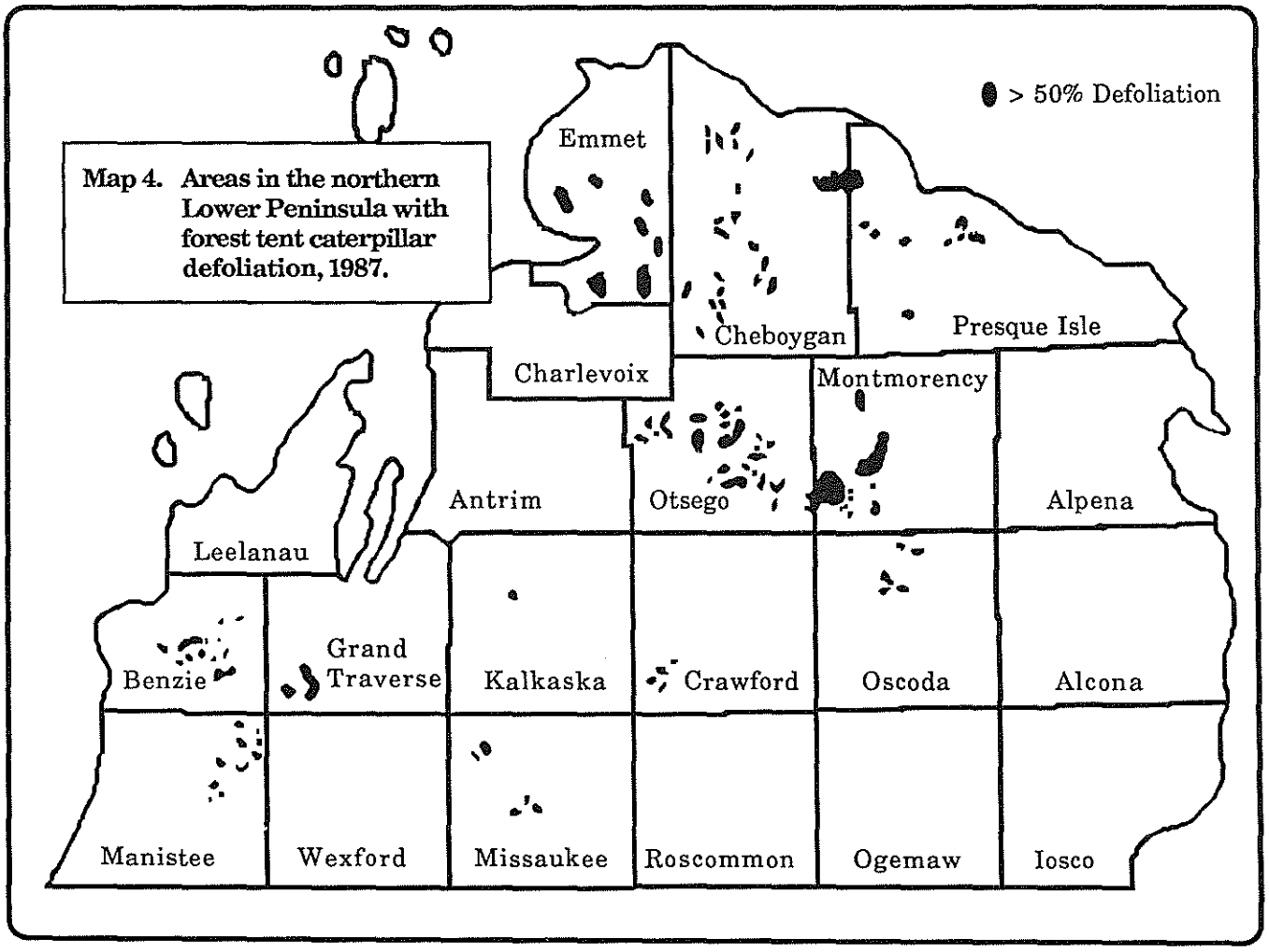
(*Malacosoma disstria*)

Although we had noticed an increase in tent caterpillar populations each of the last three years, it came as quite a surprise when we tallied 28,412 acres of defolation in 1987. Northern hardwoods, some aspen and oak were heavily defoliated in the northern sections of Region II. Sixteen counties showed defoliation that was detectable from aircraft (Table 5 and Map 4).

Maple usually suffers significant growth loss and reduced sugar production as a result of tent caterpillar outbreaks. Tree mortality is usually minimal and we do not normally recommend control. However, defoliated trees did not refoliate well in 1987 due to limited moisture. An additional season of defoliation and low rainfall may lead us to consider treating some threatened stands with an insecticide. *Bacillus thuringiensis* remains the material of choice because of its minimal environmental consequences.

Table 5. Forest tent caterpillar defoliation, 1987.

Ownership	Acreage
State	5,275
Federal	160
Private	22,527
Total	28,412



Map 4. Areas in the northern Lower Peninsula with forest tent caterpillar defoliation, 1987.

GYPSY MOTH

(*Lymantria dispar*)

Total acreage defoliated by the gypsy moth in Michigan decreased dramatically in 1987. Greater than 50% foliage loss was observed on 39,443 acres. This total acreage was a 39% reduction from the previous year's tally. The decrease was due in part to 30,955 acres treated with insecticides in Midland and Isabella counties. Naturally occurring population regulators also played a significant role in this reduction in untreated areas.

The center of gypsy moth defoliation has shifted north and west to Clare County, the hardest hit area in 1987. Many new areas in the central Lower Peninsula experienced the insect and its defoliation for the first time but levels were below 50% leaf loss - the threshold we use in our aerial surveys. Gladwin County showed visible defoliation in 1987 for the first time.

Table 6 and Map 5 summarize the results from the 1987 gypsy moth defoliation survey. Acreage is included in the total where trees have lost more than 50% of their foliage.

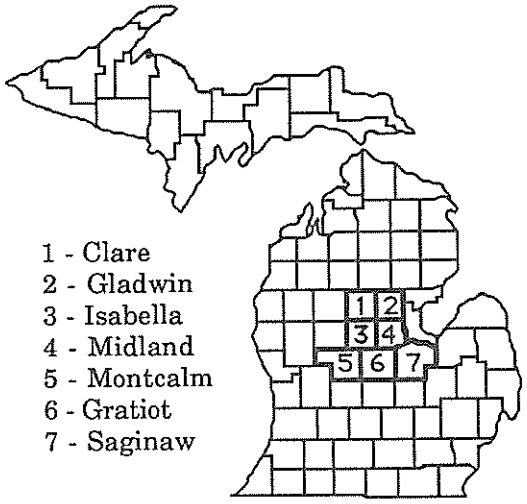
It is quite possible that portions of four to eight new counties will experience severe defoliation in 1988. Portions of Bay, Arenac, Roscommon, and Ogemaw counties appear to be quite vulnerable to the insect as indicated by high densities of gypsy moth egg masses and adults, suitable habitat, and food sources.

Tree mortality has been minimal through 1987, as Michigan has only experienced widespread, serious defoliation for three years. Gypsy moth populations seem to fluctuate wildly in any given area from year to year. Much of the defoliation has not occurred for two successive years on any given parcel of land. Fortunately, this phenomenon may work to minimize tree mortality.

Spraying high-value recreation areas is starting to become a routine activity in state forest management. In 1987 the DNR treated 35 acres of recreation land. In 1988, this treated area will likely exceed 150 acres. We have not yet observed impact from severe gypsy moth defoliation to high value timber on state land.

Table 6. Acreage with greater than 50% foliage loss due to the gypsy moth as observed during aerial surveys.

County	1983	1984	1985	1986	**1987**
Clare	0	0	0	2,040	**18,037**
Gladwin	0	0	0	0	**261**
Gratiot	0	0	0	400	**783**
Isabella	300	2,665	4,624	5,990	**3,511**
Midland	157	3,775	13,836	55,490	**16,153**
Montcalm	0	0	0	200	**305**
Saginaw	0	0	0	30	**393**
Total	457	6,440	18,460	64,150	**39,443**



Map 6. Michigan counties with gypsy moth defoliation, 1987.

DIPLODIA TIP BLIGHT

(*Diplodia pinea*)

Diplodia is usually an ornamental pest on Austrian pine. This year, we had a severe infestation in a four-year-old red pine plantation in Roscommon County. In one portion of the plantation, 50 to 60% top kill occurred with 20 to 30% tree mortality. This damage may also be associated with the dry conditions throughout the spring and summer.

Dr. Adams discusses the statewide situation with *Diplodia* on pages 25 and 26 of this report.

SPECKLED GREEN FRUITWORM

(*Orthosia hibisci*)

This pest was found throughout the northern Lower Peninsula in 1987. We found it active with another forest defoliator, the basswood leafroller (*Pantographa limata*), selectively defoliating basswood trees in hardwood stands in Montmorency County.

This insect spends the winter in the soil as a pupa and emerges as a moth in late April or early May. Larvae are present through spring and early summer. The green speckled fruitworm is not usually found in large numbers on forest trees.

SADDLED PROMINENT

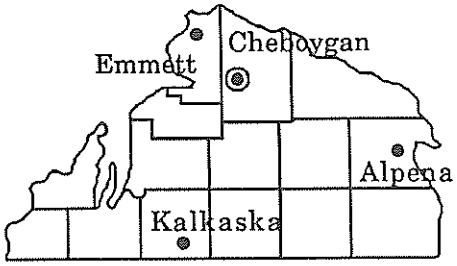
(*Heterocampa guttivitta*)

Saddled prominent populations were undetectable in 1987. Populations have been decreasing since 1984 and have finally reached endemic levels.

REDHEADED PINE SAWFLY

(*Neodiprion lecontei*)

We detected redheaded pine sawfly activity in four state-owned plantations in the northern Lower Peninsula this year (Map 7). We found larvae in three plantations and damage from sawflies the previous year in the fourth plantation. Our scouts reported 93% top kill in one plantation in Kalkaska County which we will re-evaluate next year.



- Plantations with active redheaded pine sawfly populations
- ◉ Treated plantation

Map 7. Redheaded pine sawfly in the northern Lower Peninsula, 1987.

The risk of loss to one of the three plantations infested with larvae was severe enough to warrant treatment. We treated 57 acres with emulsible malathion at 0.8 pints per acre using a mist blower mounted on a tractor. We were unable to detect any live larvae after treatment.

JACK PINE BUDWORM

(*Choristoneura pinus*)

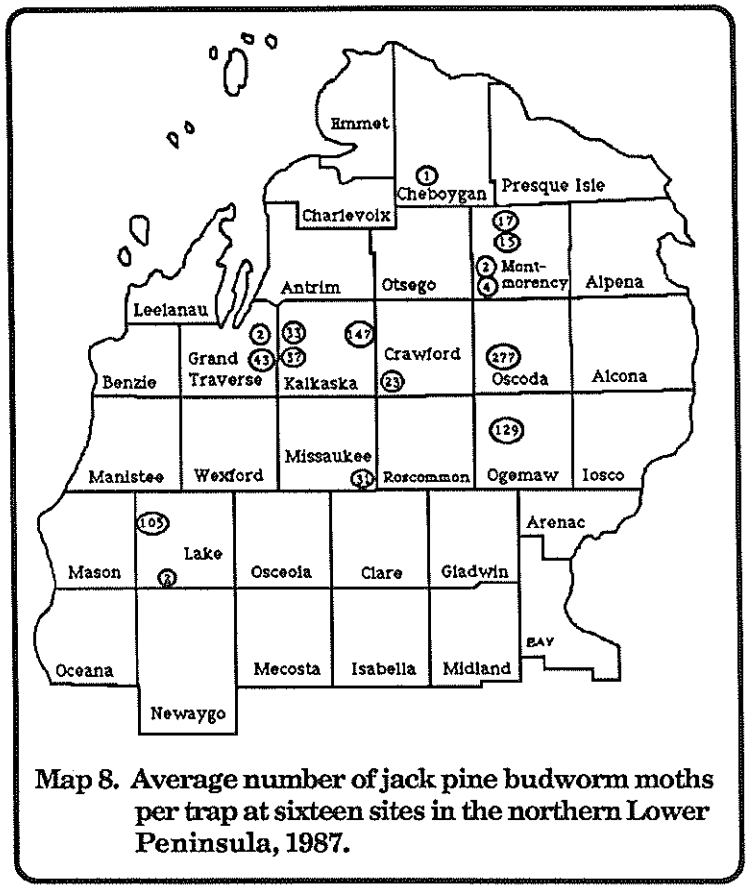
Jack pine budworm populations remain at very low levels regionwide. Larval populations in some stands in Ogemaw County were significantly higher than the regional average, although these areas are few and infrequent.

Pheromone-baited traps were set at 16 sites in the northern Lower Peninsula. Map 8 shows the average number of jack pine budworm moths per trap captured in 1987. Three traps were set per site. Trap catches averaging more than 45 moths per trap are indicative of noticeable populations. The average number of moths per trap exceeded 100 at four sites.

WHITE PINE WEEVIL ON JACK PINE

(*Pissodes strobi*)

The white pine weevil is one of our most significant plantation pests. In 1987, we found between 0 and 77% of the leaders damaged by the white pine weevil in surveyed jack pine plantations. The median per cent weeviling rate for the northern Lower Peninsula was 43%, an 11% increase over last year's median damage rate (Table 7). At this time, we are unable to project the long term losses that might result from weeviling (see pages 54 to 55 for more information on white pine weevil damage).



Map 8. Average number of jack pine budworm moths per trap at sixteen sites in the northern Lower Peninsula, 1987.

Table 7. White pine weevil damage survey results, 1987.

County	Location	Acres	% Weeviling
Alpena	31N,7E,S8 S1/2S1/2SENE,W1/2NESE, SENWSE,NESWSE	44	15
Cheboygan	35N,2W,S27 SWNW	33	49
Cheboygan	35N,2W,S34 N1/2NW,SWNW,NWSW	145	43
Crawford	25N,3W,S10 S1/2NWNE	95	74
Crawford	25N,3W,S11 NENE, N1/2SENE	50	53
Crawford	25N,4W,S26 E1/2E1/2NENE,SWSENE, NESENE	25	74
Crawford	25N,4W,S28 SENW	35	78
Crawford	25N,4W,S32 E1/2SE, NWSE	84	66
Crawford	25N,4W,S33 SWSE,SESW	65	76
Crawford	26N,3W,S27 E1/2E1/2NW,W1/2W1/2NE	85	74
Crawford	26N,3W,S27 E1/2SENE	25	70
Crawford	26N,3W,S27 E1/2N1/2NW	48	72
Crawford	26N,4W,S3 S1/2	175	40
Crawford	26N,4W,S4 S1/2NENE,W1/2SENE, S1/2SWNE,W1/2NWSE	60	76
Crawford	27N,2W,S26 S1/2SW	59	63
Gladwin	20N,5W,S29 E1/2SW,SWSW	44	0
Iosco	24N,9E,S19 N1/2NENW	--	20
Iosco	24N,9E,S19 SWSWNW	--	28
Kalkaska	27N,8W,S15 N1/2NENWSE,SESWNE	19	29
Kalkaska	27N,8W,S32 N1/2NE,SWNE	110	54
Lake	18N,11W,S18 NWSE	35	31
Lake	18N,12W,S7 W1/2NWNW	68	26
Lake	18N,12W,S7 SWSW	43	60
Lake	19N,12W,S16 N1/2SWSE,N1/2SESW	48	50
Lake	19N,12W,S18 W1/2W1/2SW	30	30
Lake	19N,12W,S32 W1/2SE	80	27
Lake	19N,12W,S32 SWNW,NWSW	25	14
Lake	19N,12W,S32 W1/2W1/2	28	15
Lake	19N,12W,S6 SENENE	15	56
Lake	19N,13W,S13 NWSW	39	41
Lake	19N,13W,S14 E1/2SESE	20	42
Lake	19N,13W,S24 NWNW	18	5
Lake	20N,12W,S19 SESW	39	55
Lake	20N,12W,S30 N1/2NE	65	25
Lake	20N,12W,S30 NESE	25	50
Montmorency	29N,1E,S15 SWNW,S1/2NWNW	56	40
Montmorency	29N,1E,S4/9 SWSESW;N1/2N1/2NWNW S1/2NWNW	8	0
Montmorency	29N,2E,S2 SWNW,N1/2SW	105	54
Montmorency	29N,2E,S30 N1/2N1/2SW	38	61
Montmorency	31N,2E,S7 SENENW,SWNWNE	12	0
Montmorency	31N,2E,S12 SWSESE,NESWSE	20	0

Continued on the next page.

Table 7. White pine weevil damage survey results, 1987. (Continued)

County	Location	Acres	% Weeviling
Montmorency	31N,3E,S13 W1/2E1/2NE,E1/2W1/2NE, NENWSE,NWNESE	92	0
Montmorency	31N,4E,S17 N1,2SESE	21	0
Montmorency	31N,4E,S19 N1,2NWNW	40	33
Montmorency	31N,4E,S20 E1/2NW	96	32
Montmorency	31N,4E,S7/18 S1/2S1/2SW;NW,SWNE,NWSW	182	29
Montmorency	32N,4E,S4 SESENE	10	6
Ogemaw	22N,1E,S2 SWNW	16	0
Ogemaw	23N,1E,S34 S1/2SW	37	0
Ogemaw	23N,1E,S34 SESE	10	0
Ogemaw	24N,2E,S15 NE	85	0
Ogemaw	24N,2E,S23 W1/2SW	60	70
Oscoda	27N,1E,S16 S1/2NENW,N3/4SENW	58	2
Oscoda	27N,1E,S21 S1/2SENE	20	4
Oscoda	27N,1E,S36 E1/2SESW,SWSWSE	23	3
Oscoda	27N,2E,S17 NE	115	7
Oscoda	27N,2E,S5 SWSESW	150	25
Oscoda	27N,2E,S5 W1/2NW,W1/2SENW	--	37
Oscoda	27N,2E,S5 W1/2W1/2NE		35
Oscoda	28N,2E,S18	11	9
Oscoda	28N,2E,S19 N1/2N1/2NWNW	10	14
Otsego	29N,1W,S10 S1/2NW	63	53
Otsego	29N,1W,S10 S1/2S1/2NE,N1/2SE	58	50
Otsego	29N,1W,S16 E1/2W1/2SE	27	0
Otsego	29N,1W,S16 N1/2NE	63	68
Otsego	29N,1W,S16 SWSW,S1/2NWSW	19	0
Presque Isle	34N,4E,S7 NENESE,SWSWNE,NENENE	25	12
Presque Isle	34N,4E,S8 NWNW,W1/2W1/2SE,S1/2SENW	69	13
Presque Isle	35N,3E,S16 N1/2NE	78	67
Presque Isle	35N,3E,S35/36 S1/2SENE,NESE;W1/2 SWNW, W1/2NWSW	90	49
Roscommon	21N,SW,S25 NENW,N1/2SWNE,W1/2NENE	84	0
Roscommon	21N,4W,S20 N1/2SENW	27	20
Roscommon	21N,4W,S20 S1/2NENE	27	22
Roscommon	21N,4W,S20 N1/2SENW	27	20
Roscommon	22N,3W,S35 SWSWSW,NESWSW	15	2
Roscommon	23N,1W,S25 NWSE	40	47
Roscommon	23N,1W,S25 SENE	40	54
Roscommon	23N,1W,S25 SWSW	32	39
Roscommon	23N,1W,S36 NESE	40	40
Roscommon	23N,1W,S36 S1/2NW	70	51
Roscommon	23N,1W,S36 S1/2NW,NESE,NWNE	116	46
Roscommon	24N,2W,S17 S1/2S1/2NW	30	60
Roscommon	24N,2W,S22 W1/2NWSE	20	43

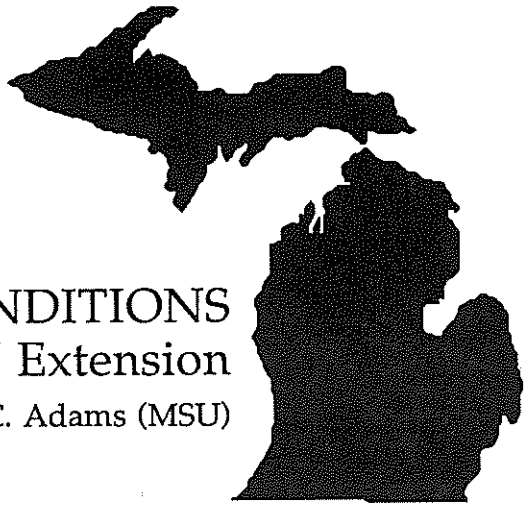
Table 7. White pine weevil damage survey results, 1987. (Continued)

County	Location	Acres	% Weeviling
Roscommon	24N,2W,S22 SWSW	35	25
Roscommon	24N,2W,S22 E1/2NENE,SENE	54	37
Roscommon	24N,2W,S23 S1/2NWNW,W1/2SENW	60	57
Roscommon	24N,4W,S4 SWNE,NENE,S1/2NW, N1/2SW	323	60
Roscommon	24N,4W,S5 N1/2NWSE	36	68
Roscommon	24N,4W,S5 E1/2NW	97	63
Roscommon	24N,4W,S5 E1/2NWNE	25	47
Roscommon	24N,4W,S5 E1/2NE	25	72
Roscommon	24N,4W,S5 NESE,S1/2NWSE	80	49
Roscommon	24N,4W,S6 S1/2SWSE	18	49

MINOR PEST PROBLEMS IN THE NORTHERN LOWER PENINSULA - 1987

PEST	HOST(S)	COUNTY	REMARKS
Aphids	Jack pine, Scots pine	Regionwide	Commonly present in young jack pine, sometimes causing leaders to wilt.
Armillaria root rot *(Armillaria mellea)*	Jack pine, red pine	Regionwide	Scattered single tree mortality in young pine plantations.
Bruce spanworm *(Operophtera bruceata)*	Sugar maple, beech, other hardwoods	Emmett and Cheboygan counties	Complete understory defoliation of northern hardwoods -- quite scattered.
Eastern pine shoot borer *(Eucosma gloriola)*	Scots pine, jack pine, red pine	Regionwide	Common in young pine plantations.
Fall cankerworm *(Alsophila pometaria)*	Northern hardwoods	Northern counties	Contributed to heavy, localized defoliation. Associated with linden looper.
Gall rusts *(Cronartium quercum)*	Jack pine, Scots pine	Regionwide	Common in jack pine areas.
Greenstriped mapleworm *(Dryocampa rubicunda)*	Sugar maple	Ogemaw County	One 40-acre patch of defoliation was noted east of Clear Lake.
Hypoxylon canker *(Hypoxylon mammatum)*	Aspen	Regionwide	Common in aspen stands.
Linden looper *(Erannis tiliaria)*	Northern hardwoods	Northern counties	Associated with fall cankerworm.
Mountain-ash sawfly *(Pristiphora geniculata)*	Mountain ash	Regionwide	Common problem on mountain ash.
Orange-humped mapleworm *(Symmerista leucitys)*	Northern hardwoods	Manistee and Wexford counties	Small scattered infestations.

PEST	HOST(S)	COUNTY	REMARKS
Pine root collar weevil *(Hylobius radicus)*	Scots pine, some red pine	Regionwide, especially west side	Our most serious pest of Scots pine Christmas trees.
Pitch nodule maker *(Petrova albicapitana)*	Jack pine, Scots pine	Regionwide	Common in young jack pine stands. Rarely damaging.
White trunk rot of aspen *(Phellinus tremulae)*	Aspen	Regionwide	Much of our aspen is overmature and in need of harvest.



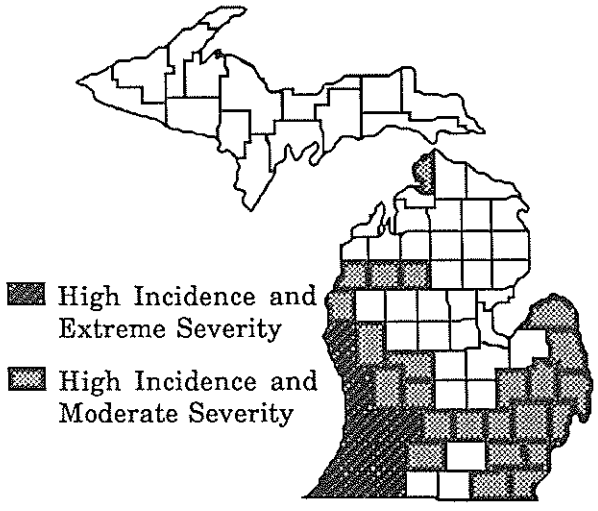
1987 DISEASE CONDITIONS
Special Contribution from MSU Extension

Gerard C. Adams (MSU)

LOPHODERMIUM NEEDLECAST

(*Lophodermium seditiosum*)

Defoliation of Scots pine (*Pinus sylvestris*) caused by the fungal pathogen *Lophodermium* was epidemic in spring of 1987, occurring at a severity unparalleled in Michigan's history. Entire plantings of Scots pine were uniformly defoliated from the terminal to ground level in some southwest and western counties of the Lower Peninsula. The most severe defoliation occurred in counties in the southwest from the Indiana border and northward along the Lake Michigan shore to Oceana County.



Map 9. Region affected by the 1987 epidemic of *Lophodermium* needle cast of Scots pine.

Managed plantations were serously damaged, while nursery stock generally escaped diseases because of routine applications of fungicides. Map 9 shows the areas with moderate to heavy defoliation in spring of 1987. Varieties (seed sources) of *P. sylvestris* varied in susceptibility as evaluated by severity of defoliation and were ranked in order of decreasing susceptibility as follows: Pike Lake, Turkish, Spanish, French, East Anglia and Highland.

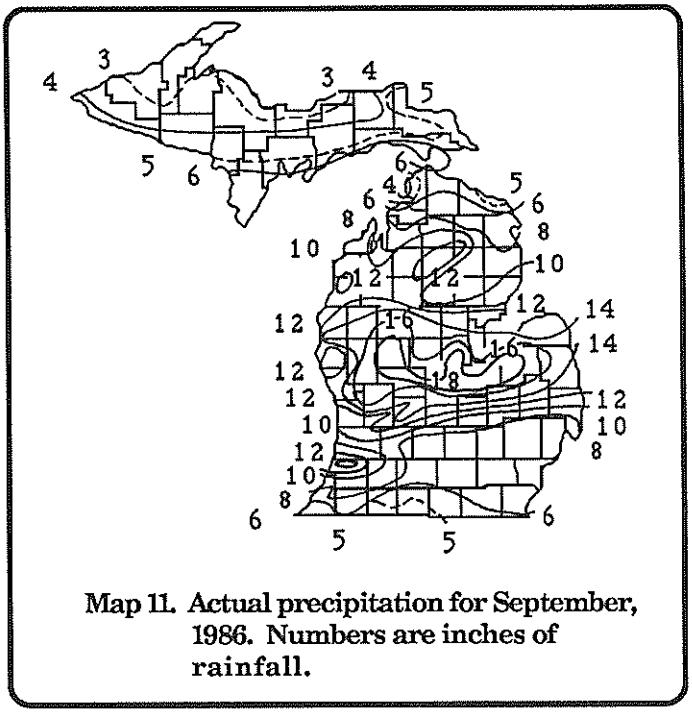
Lophodermium needle cast usually defoliates the lower third of trees and is a common problem in the northern center of the Lower Peninsula but is only rarely present in the southern Lower Peninsula. *Lophodermium* infects pine needles generally during September when spores mature and discharge into the air following rains. Needle casting occurs during the following April and early May.

The extreme epidemic of 1987 was caused by the extreme precipitation that occurred in September 1986 except for the north central and northwestern Upper Peninsula. Normal September precipitation (30 year average) is 3 inches for the Lower Peninsula. In September 1986, total precipitation was generally between 10 and 13 inches. Maps 10 and 11

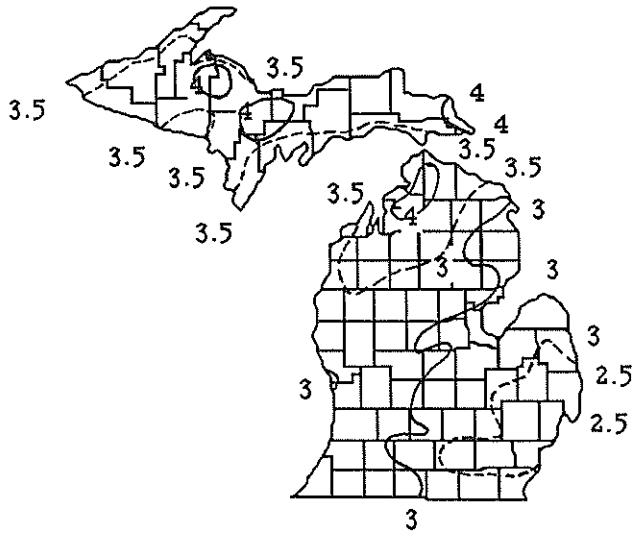
show the normal September precipitation and 1986 September precipitation, respectively.

The heavy rainfall events over a wide area of the Lower Peninsula were combined with repeated precipitation day after day and followed by unusually high temperatures. This provided ideal conditions for exceptional levels of infections. The pathogen evidently, was capable of causing infection state wide with a low-level of airborne spore inoculum as samplings of fallen needles from the previous year did not reveal visual evidence of the fruiting bodies and spores of the pathogen.

The MDA state climatologist, Fred Wurnberger, calculates a return period for the unusual September precipitation events in the 200 to 250 year RP region. Thus, a repeat epidemic of needle cast of such severity appears remote. In the fall of 1987, however, the pathogen's fruiting bodies have been unusually abundant. Therefore, less September precipitation may intitiate greater than expected infection in Fall 1987 and disease incidence in Spring 1988.



Map 11. Actual precipitation for September, 1986. Numbers are inches of rainfall.



Map 10. Normal September precipitation (30 year average). Numbers are inches of rainfall.

DOTHISTROMA NEEDLE BLIGHT

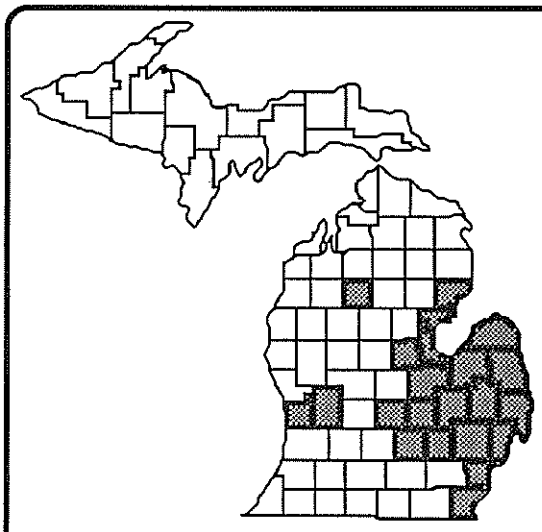
(*Dothistroma pini*)

Dothistroma needle blight is a fungal disease that primarily affects Austrian and mugo pines. Both the previous year's needles and current needles are susceptible. Previous year's needles are infected in mid-May, whereas current year's needles are infected mid-June to July. Spores are released throughout the growing season during rains.

In April 1987, Austrian pines in the southeastern Lower Peninsula were showing disease symptoms on 2 year-old needles. As the year progressed, casting of needles became apparent in late June throughout much of the southern

Lower Peninsula. Map 12 shows the distribution of severe *Dothistroma* needle blight as recorded from samples submitted to the Multidisciplinary Plant/Insect Diagnostic Clinic at MSU and samples collected during Cooperative Extension field surveys.

The incidence of *Dothistroma* blight was extensive but records are not available to make comparisons to past years. In the counties of Michigan shaded in Map 12 previous year's needles were also infected. Concurrent infection of needles for two years caused a more severe blight than in other counties and the disease greatly stressed the trees. Many of the Austrian pines showing severe *Dothistroma* needle blight later might succumb to pine wilt caused by the pinewood nematode.



Map 12. Distribution of severe *Dothistroma* needle blight on Austrian pine, 1987.

In Illinois the pinewood nematode apparently can be the sole pathogenic agent causing the death of the tree, but in Minnesota the nematode is less virulent. In Minnesota, only pines predisposed by debilitating diseases, particularly Austrain pines with *Dothistroma*, die from Pine Wilt. It will be interesting to note whether pines diagnosed with pine wilt are predominantly Austrian pines in Michigan in 1987.

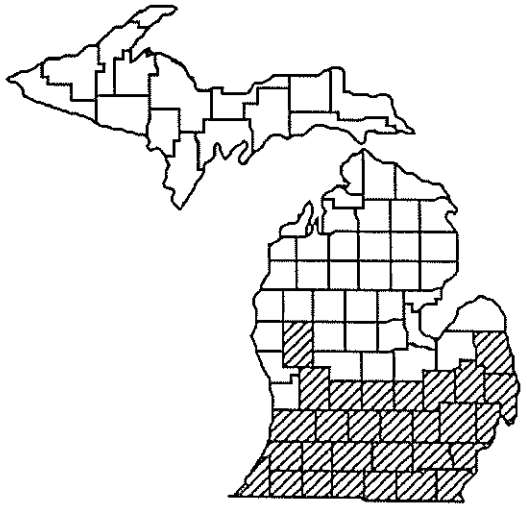
DIPLODIA TIP BLIGHT

(*Sphaeropsis sapinea*)

Diplodia tip blight of pine is a fungal disease that kills the expanding candle, the current year's growth tip. Austrian, mugo and red pine are primarily affected. The spores of the fungus are released throughout the growing season but the damage to the pines occurs just after bud break.

In April as the candle elongates the spores penetrate and infect either the sheathed needles or other shoot tissues during wet weather. By the time the needles emerge from their sheaths in mid May the infection period is over unless spittlebug injury to tissues carries infection into woody twigs.

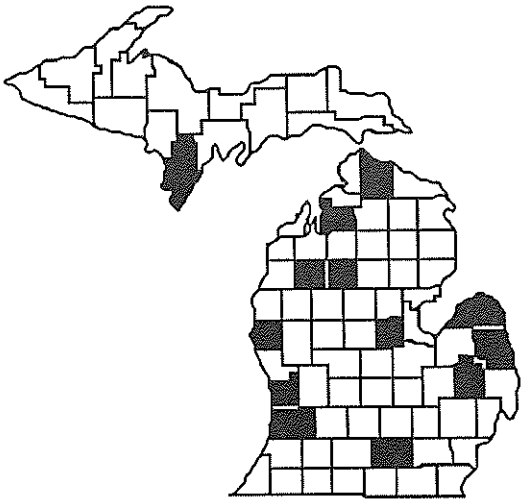
Samples of *Diplodia* tip blight on Austran, mugo and red pines submitted to the MSU Plant Diagnostic Clinic were numerous in 1987. The incidence of *Diplodia* tip blight was primarily restricted to the southern Lower Peninsula. Disease was most evident in the southeastern counties and was sometimes associated with spittlebug injury. Some samples with spittlebug injury showed dieback due to *Diplodia* exceeding 12 inches of shoot length. Map 13 shows the known counties with Austrian, mugo or red pine infected with *Diplodia* tip blight.



Map 13. Distribution of *Diplodia* tip blight on Austrian, mugo, and red pine, 1987

In the counties that submitted numerous *Diplodia* samples, rain fall was less than average during April of 1987. Thus disease incidence was expected to be low in 1987.

Much attention was focused on Austrian pines in 1987 due to the combined symptoms of infection by *Dothistroma*, pinewood nematode, and *Diplodia* and to decreased vigor caused by root rot (an abiotic wet feet). Perhaps the incidence of diagnosed tip blight appeared great because a greater number of Austrian pine samples were submitted to the Multidisciplinary Plant/Insect Diagnostic Clinic in 1987.



Map 14. Distribution of the Swiss needle cast on Douglas-fir, 1987.

SWISS NEEDLE CAST OF DOUGLAS FIR

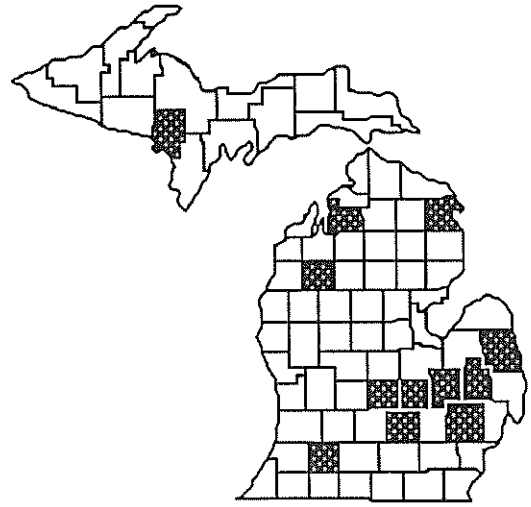
(*Phaeocryptopus gaeummannii*)

RHIZOSPHAERA NEEDLECAST OF SPRUCE

(*Rhizosphaera kalkhoffii*)

These two needle cast diseases are caused by fungal pathogens that infect newly developing elongating needles during wet weather in early June. Needles are cast one to two years after infection.

Swiss needle cast and *Rhizosphaera* are widespread in the state. Maps 14 and 15 show the distribution of the diseases in 1987 based on collected samples that contained mature fruiting bodies and spores of the pathogens on off-colored foliage. Incidence and severity of the two diseases were not unusual in 1987 and the more severe damage seen on some samples could be correlated to microclimate factors, particularly low and shaded sites.

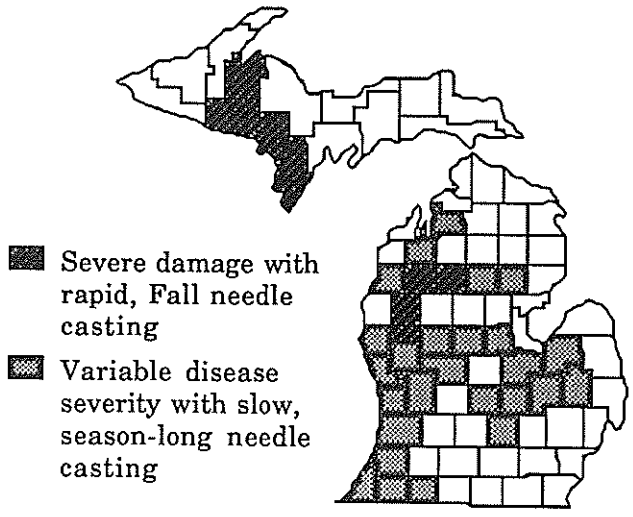


Map 15. Distribution of *Rhizosphaera* needle cast on spruce, 1987.

CYCLANEUSMA OR *NAEMACYCLUS* NEEDLECAST

(*Cyclaneusma minus*)

Our survey in 1987 was the first year of an examination of the State's managed plantations of Scots pine (*Pinus sylvestris*) for evidence of *Cyclaneusma*, a fungal pathogen causing needle cast. Evidence of *Cyclaneusma* needle cast was collected in three ways: (1) by on site inspection, and collection of the pathogen's fruiting bodies on cast needles by the author, (2) by isolation of the pathogens from needles on agar medium, and (3) by microscopic observation of the fungal fruiting bodies on cast needles mailed in envelopes by growers to MSU. Map 16 shows the counties of Michigan in which *Cyclaneusma* was found in 1987.



Map 16. Distribution of *Cyclaneusma* needlecast on Scots pine, 1987.

Cyclaneusma was also found to occur on Austrian pine (*Pinus nigra*) in Michigan in 1987. The extent of occurrence and severity could not be readily determined due to the infrequent occurrence of the fungal fruiting body on the cast needles of *P. nigra*.

Prior to the survey the disease was believed to be of rare occurrence in Michigan and to be causing insignificant damage to Scots pine. Only a few growers of managed plantations had observed significant defoliation that they attributed to *Cyclaneusma*.

We found varying symptoms and levels of damage in the surveyed plantations. For example, in the Lower Peninsula south to Wexford County fruiting bodies were generally abundant on cast needles and infected trees were thinly foliaged particularly in the lower third of the tree. However, needle casting at any particular time of year was not obvious to an observer.

Needle casting was occurring especially in Fall months but was not readily apparent because individual needles were being cast throughout the growing season. In the Lower Peninsula north to Wexford County the fruiting bodies on cast needles were rarely observed, however, the fungus could often be more readily isolated from needles onto agar culture. High levels of infection were discovered in this manner in Ogemaw County. Again, casting was not obvious in the Fall except in Missaukee County.

Symptoms in the fall of 1987 in the Upper Peninsula were dramatically apparent. The needles were cast in great numbers in a short period of time in September. Furthermore, the needles first turned a bright yellow with distinct bands of brown just prior to the casting. Two- and three-year-old needles were cast at the same time. Much of the yellowing and casting of needles in fall in the Upper Peninsula was attributed by casual observers to a normal shedding of old needles aggravated by drought.

Isolations of the fungal pathogen from casting needles revealed that yellowing of needles without the characteristic banding patterns is attributable to normal shedding

of old needles, but banded yellow needles were being seen because of disease in Scots pines. Red pines (*P. resinosa*) casting reddish brown banded needles in September were not infected with *Cyclaneusma*.

We found *Cyclaneusma* to be endemic in Michigan and believe that it is causing a significant decrease in the quality (grade) and marketability of Scots pine Christmas trees. *Cyclaneusma* like all fungal pathogens requires many hours (24 to 48) of leaf wetness to infect. Rapid drying of leaf surfaces kills spores that have failed to penetrate the leaf. The effects of the disease on Scots pine which are not sheared are probably less severe since infection would be reduced by a more rapid drying of exposed needles following rainfall.

Cyclaneusma, unlike *Lophodermium*, can infect needles at any time of the year when rain is present. For this reason, some regions of the state exhibit needle casting during a different time of the growing season than other regions. Also, some infected trees are casting needles throughout the year at low and unnoticed rates since infection the previous year occurred throughout the year at a low rate.

EXTENSION REPORTS
Forest Pest Management in Michigan

LYME DISEASE: AN EMERGING HEALTH PROBLEM

Glenn R. Dudderar (CES)

Lyme disease is an immune-mediated inflammatory illness caused by a spirochete bacterium, *Borrelia burgorferi.* This vector-borne disease is transmitted primarily by the tick, *Ixodes dammini,* although other ticks may be involved. The causative organism has also been isolated from horse flies, deer flies, and mosquitoes, but it is not known whether these insects can cause infection in humans or animals.

Lyme disease in humans is characterized by a distinctive rash, called erythema chronicum migrans (ECM). ECM usually begins 3 to 21 days after an individual is bitten by an infected tick. One or more small, red papules appear at or near the bite site. The papule expands rapidly and lightens or clears centrally, producing a unique annular lesion. If left untreated, the lesion may continue to expand for 1 to 12 weeks and reach 70 cm (27.5 in.) in diameter. Other symptoms include fever, headache, nausea, stiff neck, and muscle and joint pain. Some patients subsequently develop serious arthritic, neurologic, and cardiac complications weeks or months after the initial infection. Up to one-third of these patients may not have had the earlier characteristic ECM rash. Treatment with tetracycline, penicillin, or erythromycin has been shown to shorten the duration of Lyme disease and to prevent serious complications.

Lyme disease has only been recognized in the United States since about 1975. The Centers for Disease Control began keeping records on Lyme disease in 1980. They note that the number of reported cases increased from 226 in 1980 to 1,498 in 1984. Lyme disease primarily occurs in three recognized endemic areas in the United States: the coastal areas of the northeast especially in Connecticut, New York, and New Jersey; the west especially in Oregon and California; and in the midwest in Minnesota and Wisconsin. The number of reported cases in the endemic areas has significantly increased each year over the past few years and each year additional states are reporting cases.

In Michigan, the first human case of Lyme disease contracted within the state was reported in 1985. Four additional cases were reported in 1986. All of these cases appear to have been contracted in Menominee County.

The incidence of Lyme disease has significantly increased and spread throughout Wisconsin. In recent years, more Lyme disease cases have been

reported outside the original endemic area in northwest Wisconsin with a distinct movement to the east and south. The number of reported human cases of Lyme disease has increased as shown in Table 8.

Table 8. Number of reported cases of Lyme disease in Wisconsin, 1980-1986.

Year	No. reported cases
1980	22
1981	14
1982	46
1983	64
1984	163
1985	128
1986	> 400

The total for 1986 is an estimate from the Wisconsin Health Department.

A preliminary tick survey coordinated by the College of Veterinary Medicine at Michigan State University during 1986 showed that the primary tick vector, *Ixodes dammini*, as well as other tick species are found throughout the west and central Upper Peninsula. Ticks also occur in the Lower Peninsula. Serologic evidence of Lyme disease was found in two dogs tested in the Lower Peninsula during 1986.

Based upon the continued increase in the number of cases of Lyme disease in states where it occurs, the spread of Lyme disease cases to new areas, and the dramatic increase in the number of Lyme disase cases in Wisconsin during 1986, we may expect to see a similar increase in cases and spread of Lyme disease in Michigan.

To prevent contracting Lyme disease, I recommend:

1. Avoiding areas of known tick infestation.
2. Using protective clothing of tightly woven material with long sleeves and pants; tuck pants into boots or socks.
3. Using tick repellent (Deet or permethrin) on exposed skin and around cuffs.
4. Showering and inspecting for ticks as soon as possible after leaving tick-infested areas.
5. Removing attached ticks as soon as possible. Use tweezers clamped close to the mouth parts and pull with steady even pressure until the tick releases its hold. If tweezers are not available, use fingers covered with a tissue. Wash area of bite and hands thoroughly after tick removal. If the tick's mouth parts break off and remain embedded in the skin, seek a physician to remove the mouth parts.

ROUNDWORM IN RACCOONS AND SKUNKS

Glenn R. Dudderar (CES)

Both skunks and raccoons are often infected with an intestinal roundworm of the genus *Baylesascaris*. The roundworms are transmitted through the ingestion of fecal matter. Although the roundworms only occasionally cause problems in their normal hosts (such as intestinal blockage or debilitation during food shortages), they may cause nerve damage and subsequent disorientation, blindness or death in abnormal hosts by migrating from the intestines to nervous tissues.

Therefore, no wild animals, especially canines (fox, coyote), mustelids (skunk, mink) or raccoons should be allowed to contaminate livestock feed such as stired grain, hay or silage. Further, if these wild animals are handled, hands and clothing should be washed to prevent infection. It is obvious, then, why wild animals, should not be treated as pets, especially by young children who are not likely to practice good personal hygiene. Unwormed domestic canines (dogs) have similar parasites that can cause similar problems.

PESTICIDE EDUCATION

Roger Mech (CES),
Karen Potter-Witter (MSU),
Glenn R. Dudderar (CES), and
Frank Sapio (DNR)

Recently, much attention has been given to the fate of pesticides in the environment and the chronic effects of pesticides on human health. Proper pesticide use has been identified as a key to minimizing these hazards. In response, a major effort is underway to improve the State's pesticide applicator training and certification program. The Cooperative Extension Service at Michigan State University, in cooperation with the Michigan Department of Agriculture, is working to improve the education component by developing a more effective information delivery system.

The manual for private applicators and the manual for commercial applicators has been combined into a single manual. This streamlined version emphasizes concepts and principles of integrated pest management in regards to safe use of pesticides. The manual provides the necessary information for an applicant to qualify for private certification in Michigan. It will be available in spring, 1988.

Category manuals are being revised on a priority basis. These manuals provide the additional information an applicant must know to qualify for commercial certification in a specific category. "Urban Pest Management for Residential and Institutional Structures" has been identified as the highest priority area based on number of applicators and pesticide use. This manaual will be available in 1988.

Applicator recertification will emphasize pesticide education workshops, providing an alternative to written examinations. Sessions will be held periodically throughout the year at various locations throughout the state. The Michigan Department of Agriculture will monitor attendance and register credits.

CHRISTMAS TREE PRODUCTION

Roger Mech (CES),
Karen Potter-Witter (MSU),
Glenn R. Dudderar (CES), and
Frank Sapio (DNR)

Michigan Christmas tree growers marketed an estimated 5.3 million trees in 1987. These growers are experiencing increasing competitive pressure from souther and western producers, as well as artificial tree manufacturers. To remain viable, it is critical that they minimize costs while maximizing quality.

A series of seminars on investment analysis was offered to help growers evaluate the cost effectiveness of pest management operations. A computer model was used to help illustrate actual case studies of various integrated pest management and "calendar spray" control scenarios. Proper timing and monitoring were shown to be low cost, effective methods of reducing costs and improving tree quality.

Future seminars will cover other components of Christmas tree production, including weed control, site preparation, and shearing.

DEER DAMAGE

Roger Mech (CES),
Karen Potter-Witter (MSU),
Glenn R. Dudderar (CES), and
Frank Sapio (DNR)

In recent years, damage to crops caused by foraging deer has increased to serious levels in certain crops, including dry beans, fruit, and Christmas trees. Several factors are responsible, including increased deer numbers, mild winters, and heavy fall rains which slowed harvesting efforts.

The Michigan Department of Natural Resources appointed an ad hoc task force in 1987 to identify wildlife management options associated with deer and

agriculture in the state. Agencies represented by the task force included MSU Cooperative Extension Service, Michigan Department of Agriculture, the Upper Peninsula's Sportsmen's Alliance, the Michigan Farm Bureau, and the Michigan United Conservation Clubs.

Several management alternatives were implemented during the 1987 deer season. For example, changes in the 1987 hunting regulations were aimed at boosting the harvest of does and fawns on private land, particularly those sustaining heavy crop damage. As a result of recommendations from the task force, the DNR raised the number of management units open for anterless permits, increased the number of Hunter's Choice and Landowner's Limited permits, and allowed two anterless deer per permit in some units.

The task force is currently addressing long-range management alternatives, some of which may be implemented as early as 1988.

CHRISTMAS TREE PEST MANAGEMENT

Jill O'Donnell and
Norm Myers (CES)

Montcalm, Newaygo, and Mecosta counties have had an ongoing Christmas tree management program since 1986. Twilight tours and workshops were offered yearly to provide growers with information on tree production, insect and disease management, weed control, and investment analysis.

In the spring of 1987, we surveyed area Christmas tree growers about their pest management needs. Initially, we were looking towards an integrated pest management scouting program that would be supported by growers. Responses from the survey showed interest in the program but not many growers were willing to make the commitment. However, growers responding to the survey indicated a strong interest in a weekly pest management newsletter.

Results from the assessment spurred us to publish a weekly subscription newsletter which runs for 20 weeks each year. Weekly features included degree-day information, pest profiles, weekly scouting reports, and pesticide updates. Each agent cooperated with individual growers and scouted several plantations in our respective counties. From these weekly surveys, we were able to summarize the status of current pests and project which pests to anticpate in the coming weeks.

The newsletter was received enthusiastically with the scouting report rated as the most useful part overall. Growers stated that it helped them make more timely, knowledgeable decisions and improve the overall quality of their trees.

Current plans for 1988 are to continue with a new and improved newsletter. We will place additional emphasis on helping growers to further understand the function and importance of degree days, pest life cycles, pest identification and control, marketing, and labor.

STATEWIDE GYPSY MOTH EDUCATION PROGRAM

Bruce Montgomery (MSU)

The MSU Cooperative Extension Service and Agriculture Experiment Station continued funding of the Gypsy Moth Education Program for Michigan. The Michigan Department of Natural Resources had sponsored the program for the previous 18 months. A number of educational materials and activities have been completed since March 1986, including:

- Annual Reports of the Gypsy Moth Technical Committee
- Periodic newletters on gypsy moth management activities
- News releases
- Television and radio appearances
- Videotapes

Workshops
Field trips
Magazine articles

In addition to refinement and addditions to the above materials and activities, activities planned for the 1988 Gypsy Moth Education Program include:

Leaflets
Manuals
Slide tape programs
Displays
Gypsy moth riker mounts
Posters

Many people have cooperated in the Gypsy Moth Education Program. A number of forest pest specialists have made presentations at workshops, meetings, and conferences and have provide written materials and other information for the production of leaflets, the manual and the annual reports.

In particular, Roger Mech (CES) and Gary Simmons (MSU) have contributed numerous hours to the education effort. John Witter and Charlotte Young (U of M) have made valuable contributions to the overall program with their education and research efforts in urban and suburban areas.

The program is currently at a major crossroad. Funding may not be available after September 1988. Work is continuing to secure funding for the program and for gypsy moth research projects.

RESEARCH SUMMARIES
Forest Pest Management in Michigan

POPLAR-GALL SAPERDA

Louis Wilson and
Lincoln Moore (USDA Forest Service)

Attacks of the poplar-gall saperda, *Saperda inornata*, on hybrid *Populus* were monitored in a stand for four years after planting. More than 60 percent of the whips were attacked the first year, resulting in a mean of 1.6 galls per tree (range: 0 to 8). Branch attacks superseded stem attacks in the third and fourth years. The location of saperda attacks indicated the insects' preferrance for certain branch and stem sizes.

In the first year, all galls formed on the lower two-thirds of the whips and on a few of the largest branches. In the second year and thereafter, saperda adults chose egg-laying sites higher on the stem and further out on the lower branches. By the fourth year, the lower 3.5 m of the stem was unacceptable to saperda attack.

Saperda injury significantly reduced height because of leader breakage after the second-year attacks. However, the injured trees grew rapidly and recovered much of the height in the third and fourth years. Saperdas killed 4 percent of the trees during the study, but this was no more than would be expected in a newly-established stand. Saperda, at least at the population levels studied, does not seem to greatly affect hybrid *Populus* growth or reduce biomass.

SARATOGA SPITTLEBUG

Robert Heyd (DNR) and
Louis Wilson (USDA Forest Service)

The saratoga spittlebug continues to be a problem insect to pine trees when its alternate hosts are abundant. Reducing the alternate hosts with herbicides is a viable option for spittlebug control. Mistblower treatments with Roundup® or Krenite® significantly reduced sweet-fern the first year. Thereafter, stems resprouted in the second and third year inversely to the dosage level.

On the average, all treatments reduced sweet-fern from 92 to 100 percent in the first year. After three years, sweet-fern reduction varied from averages of 58 to 90 percent. Roundup® maintained a greater stem reduction at lower dosages than Krenite®. Also, Roundup® suppressed blueberry, grasses, and other ground cover for at least three years while these plants began to re-invade the Krenite® treatment areas in two years. Krenite® burned the foliage of some of the pines along the mistblower swath path; Roundup® caused no injury. Overall, a 1- or 2-quart per acre dosage of Roundup® gave the best treatment for long-lasting suppression of alternate hosts.

EFFECTS OF DROUGHT ON INSECT OUTBREAKS

William Mattson and
Robert Haack (USDA Forest Service)

Under normal weather conditions, forest pest populations are commonly kept at endemic levels by their natural enemies and various tree resistance mechanisms. However, outbreaks of several forest insects often occur during periods of environmental stress, such as drought. Insight into how drought influences insect outbreaks may allow development of management strategies for implementation during periods of environmental stress.

A conceptual model was developed to explain how drought may provoke insect outbreaks. The model showed that drought affects almost all physiological processes of plants; including their spectral quality, temperature, and acoustic emmissions; their mineral, nutrient, and allelochemical concentrations; and their wood-healing abilities.

Overall, the model indicated that drought-stressed trees become behaviorally more attractive and acceptable to insects as well as physiologically more suitable and susceptible to insect attack. It also showed that the nutritional and thermal changes induced by drought may enhance insects' detoxification and immune systems and favor their mutualistic organisms, but may adversely affect their natural enemies.

EASTERN LARCH BEETLE

Robert Haack and
Richard Blank (USDA Forest Service)

This bark beetle killed a large number of tamarack trees in provenance plantations at the Kellogg and Russ Forests (Map 17) during 1985 and 1986. The plantations are being evaluated for resistant seed sources. Beetles tended to attack large diameter trees preferentially.

NOSEMA FUMIFERANAE AND *BACILLUS THURINGIENSIS*

Leah Bauer (USDA Forest Service)

Research on the interaction between the spruce budworm and the microsporidian, *Nosema fumiferanae*, resulted in the quantification of disease impact on transovarially infected F1 progeny and significant correlations between parental disease level and progeny response. Diseased larvae were found to have suppressed rates of food consumption and growth and production efficiencies, while digestive efficiencies improved. Elevated levels of dietary nitrogen increased larval disease tolerance, despite greater *N. fumiferae* spore production per milligram of insect tissue.

Diseased larvae that had been treated with *Bacillus thuringiensis* (Bt) had higher mortality rates. Healthy insects that survived Bt exposure were also more susceptible to subsequent *N. fumiferanae* inoculations.

Recently, studies undertaken to determine the susceptibility of target coleopterans to a new Bt strain (var. San Diego) found that all stages of the cottonwood leaf beetle were sensitive. A 96-hour Bt exposure period on hybrid poplar foliage was used to determine median lethal dosages and times for the last two larval stages and the adult stage. Efficacy studies against the white pine weevil are in progress.

INFLUENCE OF SPRUCE BUDWORM FEEDING ON FOLIAGE QUALITY

Robert Haack and
Richard Blank (USDA Forest Service)

1987 was the second year of this four-year project to study the effects of budworm feeding on foliar chemistry and shoot development of white spruce. In addition, budworm performance is being compared between individuals that developed on previously defoliated and undefoliated branches.

TWOLINED CHESTNUT BORER

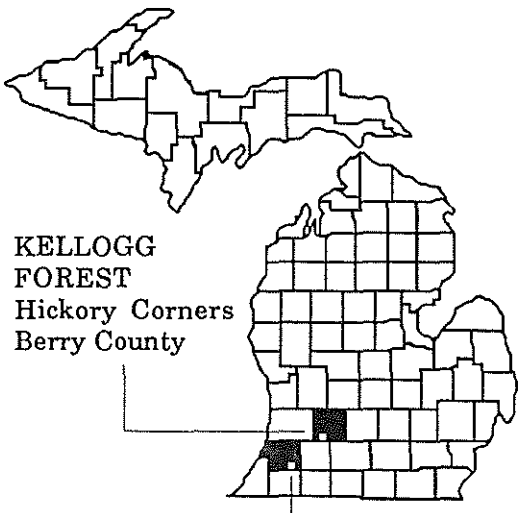
Robert Haack and
Richard Blank (USDA Forest Service)

The twolined chestnut borer continues to preferentially attack English oaks over red and white oaks at the Kellogg and Russ Forests. Root starch content, a measure of tree vigor, is being evaluated and correlated with the pattern of borer attack. Selected trees have been fertilized with 10-10-10 to see if borer attack will decrease. This borer is very active in Toledo, Ohio, where it is attacking European hornbeam. Soil aeration and watering treatments are being evaluated as techniques for reducing losses to the borer.

BRONZE BIRCH BORER

Robert Haack and
Richard Blank (USDA Forest Service)

A provenance plantation of American paper birch (from all Michigan counties in which it grows naturally) and European paper birch (growing at the Russ Forest) was evaluated for bronze birch borer damage in 1987. Borers preferentially attacked European over American birch. Moreover, considering only the Michigan seed sources of American paper birch, borer attack was greater on the Upper Peninsula seed sources than those from the Lower Peninsula.



Map 17. Locations of Russ and Kellogg Forests.

SEASONAL CHANGES IN HOST TISSUE NUTRIENTS

Robert Haack and
Richard Blank (USDA Forest Service)

Seasonal patterns in the nutrient content of sapwood, inner bark, and foliage are being determined for various species of trees growing at the Kellogg Forest. In

1987, native tamarack, European larch, Japanese larch, white ash, and white pine were selected. Host tissues were collected from April through September and will be analyzed for total nitrogen, soluble sugars, and several minerals. We plan to select from four to ten tree species each year.

ATMOSPHERIC POLLUTANT EFFECTS ON OAK-HICKORY FORESTS FROM ARKANSAS TO OHIO

Robert Haack and
Richard Blank (USDA Forest Service)

A 5-year project was initiated in 1987 to study forest tree responses to atmospheric pollutants along the "Ohio River corridor." Plots have been established in oak-hickory forests in Arkansas, Illinois, Indiana, and Ohio by scientists at Butler University (in Indiana) and Southern Illinois University. Our task is to monitor forest insect populations and their associated damage along the gradient, and then correlate these data with pollution patterns, soil data, and stand growth parameters. Much of our effort will involve monitoring defoliators and wood borers.

ULTRASONIC EMISSIONS FROM WATER-STRESSED TREES

Robert Haack,
William Mattson, and
Richard Blank (USDA Forest Service)

We received funds on a USDA competitive grant in 1987 to study the impact of ultrasonic acoustic emissions (AEs) from water-stressed pine trees on the colonization behavior of *Ips* bark beetles. Our study will investigate the water columns within the tree's conducting xylem which are held under tremendous tension. This tension increases as drought intensifies and, at some critical point, the water columns break resulting in AEs. Our model system will consist of *Ips* bark beetles and eastern white pine.

Specifically, we will record signals from water-stressed pines using ultra-sonic receivers and then test whether these AEs are attractive to adult *Ips* using ultrasonic pulsars. It may be possible that certain insects can *hear* stressed trees.

PESTICIDE TRIALS

Roger Mech (CES),
Karen Potter-Witter (MSU),
Glenn R. Dudderar (CES), and
Frank Sapio (DNR)

1. WHITE PINE WEEVIL. A test was conducted to determine the effectiveness of fall application of foliar insecticides in reducing white pine weevil damage. The test was a cooperative effort by CES and the DNR to measure the effectiveness of several synthetic pyrethroid insecticides in reducing terminal damage on young, plantation-grown jack pine. Pyrethroids have several advantages over many traditional pesticides registered for use in forest applications, particularly increased cost-effectiveness and lower human toxicity.

Test results indicate that fall insecticide sprays may offer a viable approach to management of white pine weevil. Tempo® and Mavrik® outperformed the standard Orthene® at rates tested. Ambush® performed as well as the standard. Pydrin®, although not as effective as Orthene®, also reduced damage.

Additional investigation is needed to determine re-infestation rate following treatment and actual volume loss and form losses associated with weeviling. This information will allow forest managers to calculate the cost-effectiveness of chemical control of white pine weevil.

2. PINE NEEDLE MIDGE. Lorsban® was tested to determine its effectiveness in reducing damage by the pine needle midge, a serious pest of Scots pine. When left

unchecked, this pest can cause serious degrade to Christmas trees and, in some cases, make the trees unsalable. Lorsban®, a nonsystemic, short-residual organophasphate is commonly used to control many agricultural insect pests in Michigan.

Lorsban® significantly reduced damage from pine needle midge at the rates used. Both formulations tested performed as well as the standard Pydrin®. Lorsban® performed as well or slightly better than the insecticide Mavrik®. Overall, its effectiveness and short persistence in the environment make Lorsban® a sound choice for use in a management program for pine needle midge.

MSU RESEARCH PROJECTS

Gary Simmons (MSU)

GYPSY MOTH

POPULATION DYNAMICS/BT EFFICACY: With collaboration from Phil Watson (Ferris State University) and Louis Wilson (USDA Forest Service), we have established six mixed hardwood stands containing oak in the Sanford, Michigan area. Three of the stands have been sprayed each year with B t. At 25 plots within each stand we monitor egg density, larval density, pupal density and defoliation. This work has gone on since 1986 and we plan to continue into the future.

MONITORING/SAMPLING: Collaborating with Dr. Gary W. Fowler (University of Michigan) we have developed a gypsy moth egg mass monitoring system and have tried it out in the city of Midland. Essentially, the city is subdivided into strata based on the density of tree cover. Within each stratum monitoring plots consisting of 3 white, red or mixed white and red oak trees have been established. So far, results have been encouraging. The next step is to develop a procedure for evaluating an 80 acre management unit. That work will continue.

RISK RATING/DEFOLIATION PROJECTION: This work is a collaborative effort involving Dr. Brad Parks (MSU), Dr. Stu Gage (MSU) and Mr. Tim Wirth (MSU). Using Geographic Information System technology we are refining techniques that can be used to project future defoliation by the gypsy moth.

LARVAL BEHAVIOR/FEEDING: This is part of a project being done by a doctoral candidate, David Roden. Dave is on leave from the Canadian Forest Service in Sault Ste. Marie, Ontario. In the laboratory Dave has examined preference of all stages of larvae for different colors and different diameters of artificial tree trunks. In the field he will be bioassaying the potential induceable defenses of select tree species. This work will be continuing.

WHITE GRUBS

This work was part of a Master's project done by Irene Borak. This is a collaborative project with Dr. Bob Heyd (Michigan DNR) and Dr. Louis Wilson (USDA Forest Service). In essence Irene was attempting to find a replacement insecticide for some of the chlorinated hydrocarbons that had been formerly used for white grub control. In the Upper Peninsula and in northern Wisconsin white grubs are a major deterrent to planting red and jack pine. Irene and Bob established several experimental plantations in 1987 in which promising pesticides were applied at the time of planting using a modified planter. Preliminary results showed good survival of all seedlings that had received pesticide treatment. Additional data will be taken this year and in subsequent years.

PREDACEOUS ANT STUDIES

As an outgrowth of another study a doctoral student, Nancy Campbell, is studying the foraging behavior of the thatching ant, *Formica obscuripes* (Forel). This work is being done collaboratively with Dr. Kathy Bristow (MSU) a new faculty member in Natural Science and an ant expert, Dr. George Ayers (MSU) an

apiculturist and flowering plant intercropping expert, Dr. Leah Bauer (USDA Forest Service), and Dr. Louis Wilson (USDA Forest Service). So far, results have suggested that the ants are superb predators on "naked" caterpillars and good predators on caterpillars that spin a shelter. Work in the laboratory and field will explore predatory effects on hairy caterpillars and on ovipositing adult insects. In addition, mechanisms of prey switching from aphid honeydew to insect prey will be examined.

TREFOIL INTERCROPPING STUDIES

This work is being done in collaboration with Dr. George Ayers (MSU). Experimental plantations of Scots pine Christmas trees and birdsfoot trefoil have been established at the Kellogg Farm near Hickory Corners.

The apparent advantages of the trefoil is that it provides weed control, a source of nitrogen fixation for the trees and a source of nectar and pollen for bees which may be kept on the same land. In concept, such an intercropped system could produce an annual honey crop thus providing a tree grower with a supplemental income from the land until the trees are harvested. The work with ant predators hopefully will lead to an alternative means of pest management that doesn't disrupt bee populations with harmful pesticides, but instead relies on ant colonies that are sustained by aphids on the trefoil and pest insects on the trees.

GYPSY MOTH/TREE/SITE INTERACTIONS IN MICHIGAN

John Witter,
Charley Chilcote (U of M), and
Mike Montgomery
(USDA Forest Service, Hamden, CT)

We started a three-year study in April 1987, to determine the relationships betweeen forest site factors and gypsy moth growth and survival. Four study sites representing dry and moist oak ecosystems were chosen. Data were collected on each study site for the following variables: *physiography* (% slope, aspect, position on slope, landform, glacial origin); *soil* (pH, structure, texture, soil moisture; and *vegetation* (tree species, understory vegetation, stand density).

Fourteen different tree species were examined in 1987. We will concentrate in future years on red oak, white oak, northern pin oak, black oak, bigtooth aspen, and trembling aspen. Not all tree species are present in each study site since the site characteristics vary by study site. Trees between 4 and 10 meters were selected for study. Four sleeve bags were secured on each tree and placed over the terminal part of different branches.

Ten two-day-old gypsy moth larvae were placed in each bag at the time that the oak foliage was just beginning to expand at the field sites. The larvae used in the field study were reared in our laboratory from egg masses collected from a healthy gypsy moth population located in Midland County, Michigan. Bags were examined weekly, and changed if the remaining foliage was less than 50% of its original leaf area. Larvae were weighed and counted at approximately two-week intervals. The larvae were weighed by removing them from the bags and taking them to a nearby field laboratory for weighing. They were weighed immediately and then transported back to the field site and returned to the appropriate bag. Once pupation began, bags were checked approximately every other day and new pupae were collected and weighed.

Survival of small larvae and pupae varied greatly by tree species. Early larval survival (at the end of two weeks) was the highest on witch-hazel, beech, paper birch, northern pin oak, and trembling aspen. Early larval survival was the lowest on boxelder, bigtooth aspen, sugar maple, and pignut hickory. It was very obvious that survival of small larvae on bigtooth aspen depends entirely on whether the aspen clone chosen for the study is a late or early flushing clone. The number of individual

larvae that developed to the pupal stage after initial survival (% alive after six weeks) was the highest on witch-hazel, trembling aspen, northern pin oak, white oak, black oak, and red oak. Very poor survival of larvae occurred on American elm, sugar maple, boxelder, pignut hickory, and serviceberry. Small larvae and pupae varied considerably by study site for the same tree species. We are studying these differences at this time.

The weights of the gypsy moth larvae in the field four and six weeks after hatch varied significantly by tree species. The largest larvae found after four weeks in the field were on trembling aspen (169 mg), northern pin oak (146 mg), black oak (119 mg), bigtooth aspen (113 mg), red oak (107 mg), paper birch (103 mg), and white oak (88 mg). Extremely small larval weights were recorded for the larvae that were placed on sugar maple, boxelder, American elm, black cherry, serviceberry, hop-hornbeam, and American beech. The largest larvae found after six weeks in our sleeve cages were on trembling aspen (602 mg), black oak (539 mg), bigtooth aspen (516 mg), northern pin oak (484 mg), and white oak (372 mg). There was considerable variation of larval weights within the same tree species by study site.

Pupal weights varied by sex and tree species. The highest female pupal weights were found on bigtooth aspen (1391 mg), trembling aspen (1390 mg), northern pin oak (977 mg), paper birch (947 mg), white oak (935 mg), and black oak (878 mg). The pattern of male pupal weights by tree species was similar to the female pattern for most tree species. The female pupal weights were 2.3 to 2.9 times larger than the male pupal weights. Pupal weights on the same tree species varied by study site. Larval and pupal weights also differed considerably within plots for red oak.

Preliminary analysis of the 1987 field data shows us that there are major differences in larval and pupal survival and in larval and pupal weight by tree species and study sites. We are still in the process of studying and analyzing our data from the 1987 field season to fully explain all of these differences.

OAK ECOSYSTEMS STUDIES IN SOUTHEASTERN MICHIGAN

John Witter (U of M)

A thorough understanding of oak ecosystems in Michigan is needed, to better manage oak stands in Michigan. Louie Archambault, Burton Barnes, Pat Comer, and John Witter have just completed a three-year study that: (1) developed a classification system for oak ecosystems in southeastern Michigan; (2) developed ecological species groups for the oak ecosystems of southeastern Michigan; and (3) described oak and hickory vigor in these ecosystems. This research was initiated and completed prior to the onset of any noticeable defoliation by the gypsy moth. Eleven upland ecosystems and one wetland ecosystem were classified using field reconnaissance, plot sampling, and test mapping. Each ecosystem was a characteristic combination of physiography, soil, and overstory and ground cover vegetation. The classification approach relied to a great extent on physiographic and soil variables so that it could be used in disturbed areas.

Thirteen ecological species groups were developed by using 68 herbaceous and shrub species. A continuum of groups from very dry to wet sites were identified. Nine groups were judged useful to help identify ecosystem types in the field.

The vigor of oak and hickory trees of the upland oak ecosystems was estimated. Four individual tree characteristics were used: crown condition, epicormic branching, crown ratio, and periodic basal area increment. Tree vigor was generally lower in dry ecosystems with coarse-texture soils compared to moist ecosystems with fine-texture soils. Tree mortality was low in all ecosystems. The mean relative dead basal area averaged 4.9%, ranging from 1.5 to 6.4%. The mean number of dead overstory trees averaged 6.2%, ranging from 3.9 to 9.9%. Mortality was distributed

randomly between all species, all age classes, and all dominance classes.

Cristine Spiquel, Dan Richter, and John Witter are studying the effects of increased atmospheric pollutants on plant growth and the nutrient cycling process in 42 plots in oak-hickory stands (see subsequent article on this page). Charley Chilcote, Mike Montgomery, and John Witter began a 3-year study in spring 1987 that will examine the relationships between various tree and site factors and gypsy moth growth and survival (see preceding article).

GYPSY MOTH EDUCATION AND PEST MANAGEMENT PROGRAM FOR SUBURBAN AND URBAN COMMUNITIES IN MICHIGAN

John Witter and
Charlotte Young (U of M)

Charlotte Young and John Witter have concentrated their research efforts during the last two years on: (1) which types of brochures are more useful in transferring information about the gypsy moth to the public; (2) the public's knowledge level about the gypsy moth; and (3) what motivates people to participate in gypsy moth management activities. The 1986 research studies were conducted in Ann Arbor and Harbor Springs, while the 1987 studies were conducted in Ann Arbor and Midland. Results are currently being analyzed and detailed information on this study will be available by late Fall 1988.

ATMOSPHERIC POLLUTANT EFFECTS ON FORESTS IN THE GREAT LAKES REGION

John Witter (U of M),
Kurt Pregitzer (MSU),
Glenn Mroz, Marty Jurgenson,
David Karnosky, David Reed,
Robert Stottlemyer (MTU), and
Dan Richter (Duke University)

PROBLEM/JUSTIFICATION

The Great Lakes Region is being subjected to a pronounced regional gradient of air pollutants. Based on National Atmospheric Deposition Program (NADP) data from 1980 to 1984, sulfate contained in precipitation ranges from over 35 kg/ha/yr in Ohio to less than 10 kg/ha/yr in northern Minnesota. Moreover, the gradient of total sulfur (S) deposition is probably much steeper than that indicated by sulfate deposition. Annual pH of precipitation ranges from about 4.1 in Ohio to greater than 5.0 in northern Minnesota. No major ozone gradient apparently exists in this region, due to relatively high concentrations of ozone that exist throughout the southern Great Lakes Region. For example, maximum recorded 1-hr levels of ozone exceeded 120 ppb at all sample stations in the prominent gradient of pollutant deposition in the Great Lakes Region.

Atmospheric deposition of man-made air pollutants may be adversely affecting forests in the southern Great Lakes Region. However, little reliable baseline data exist for most portions of this forested region. Data which do exist are not of sufficient quality to assess long-term ecosystem or forest productivity, and vigor can be evaluated and tested by studying hardwood forests along the steep pollution gradient in the Great Lakes Region. Since early 1985, scientist at the University of Michigan, Michigan State University, and Michigan Technological University have been planning and/or conducting research on the effects of atmospheric pollution gradient

with emphasis on the Michigan portion of the gradient. The overall hypothesis is that the pollution gradient is influencing a variety of ecosystem processes that affect forest productivity and vigor.

OBJECTIVES

During the last two years, we have used Michigan DNR research dollars and funding from USDA Forest Service, Michigan Energy and Resource Research Association (MERRA), Detroit Edison, Consumers Powers, Lansing Board of Water and Light, and General Motors to begin our studies on the effect of air pollutants on forest productivity. The Michigan DNR funding during the last 18 months has been utilized to accomplish the following specific tasks: (1) select and characterize study sites and plots along the air pollution gradient; (2) document the regional air pollution gradient; (3) assess foliar damage symptoms on ozone-sensitive species that are attributable to ambient concentrations of oxidants; and, (4) develop and initiate process field-oriented research studies to determine whether atmospheric deposition is causing fundamental changes in forest productivity and health.

APPROACH

Stands were selected in two different forest types (northern hardwood, oak-hickory) along the gradient. The sites selected were: (1) northern Minnesota near Tofte, (2) northern Upper Penisnula of Michigan near Twin Lakes, (3) northern Lower Peninsula of Michigan near Pellston, (4) northcentral Lower Peninsula of Michigan near Wellston, (5) Oceana County in central Lower Peninsula of Michigan, (6) Russ Experimental Forest near Niles in southwestern Michigan, (7) Kellogg Experiment Forests near Battle Creek in southcentral Michigan, (8) George Reserve and Radrick Forests near Ann Arbor in southeastern Michigan, and (9) Cuyahoga National Recreation Area in northern Ohio. In other words, we have long-term study sites established in 12 forest stands (six northern hardwood, six oak-hickory) at nine locations along the gradient. It took over a year to select and describe analogous stands and plots at these locations.

Precipitation chemistry data from high quality collection programs were collected and evaluated to construct a data set of precipitation chemistry within the region for SO4, NO3, and H+. A similiar effort is being made to summarize available data on ozone, SOx, NOx, and other air pollutants in the Great Lakes Region. Maps of region air quality are in process of being updated.

Aerochem Metric precipitation collectors and canopy throughfall collectors were established at key locations throughout Michigan during May and June 1987 to define precipitation chemistry in greater detail. The average weekly sulfate deposition, for the period June 30, 1987, to September 29, 1987, ranged from 0.35 kg/ha/wk near Houghton, Michigan (Upper Peninsula) to 0.64 kg/ha/wk in Oceana County (central Michigan) to 1.28 kg/ha/wk in Washtenaw County (southeastern Michigan). The average weekly nitrate deposition for the period from June 30, 1987 to September 29, 1987, ranged from 0.23 kg/ha/wk near Houghton, Michigan to 0.41 kg/ha/wk in Oceana County to 0.60 kg/ha/wk in Washtenaw County. The average weekly precipitation pH ranged from 4.98 near Houghton, Michigan to 4.41 in Oceana County to 4.18 in Washtenaw County. Our data for 1987 from the precipitation collectors and the canopy throughfall collectors showed about a 3.5-fold and 2.5-fold increase in sulfate and nitrate, respectively, from north to south along the pollution gradient in Michigan. Pronounced pH and conductivity gradients also exist.

Elevated levels of ozone and other photochemical oxidants have been commonly recorded in southern Michigan. We have initiated two types of research to evaluate whether these pollutants are causing visible foliar injury and/or growth reductions. First, an experimental plantation consisting of two ozone-sensitive and two ozone-tolerant trembling aspen clones from each of six natural populations from across the eastern United States were established in September 1986 at

Table 9. Selected hypotheses for research studies on atmospheric pollutant effects.

Hypothesis I:	The atmospheric pollutant gradient is directly related to chemistry of throughfall and soil solutions, and to cations leaching from canopies and soils.
HypothesisII:	Atmospheric deposition of S, N, and acids alters foliage elemental ratios and litter decomposition.
HypothesisIII:	Growth efficiency (stemwood production/unit leaf area) of forest stands declines as atmospheric pollution increases.
Hypothesis IV:	Inputs of atmospheric pollutants alter the pattern of allocation of carbon to leaves and fine roots.
Hypothesis V:	Rates of seedling mortality and recruitment into larger size classes decrease as atmospheric inputs increase.
Hypothesis VI:	Species richness and diversity are negatively correlated to atmospheric inputs.
Hypothesis VII:	Genetic changes due to atmospheric pollution have already occurred over the gradient such that the existing populations of trees are more tolerant to air pollutants at polluted sites than at more pristine sites.

the University of Michigan's Botanical Garden. This plantation will be evaluated monthly during the growing season for visible foliar injury and yearly for growth information.

Second, experimental plantations at Michigan State University's Kellogg Biological Station and the Russ Experimental Forest are being evaluated for ozone injury. Extensive visible foliar symptoms were recorded on black cherry in a state-wide seed source test located at the Kellogg Biological Station. Other trees in southern Michigan showing visible foliar symptoms of ozone injury included green ash, yellow poplar, sassafrass, white ash, and eastern white pine.

The process research field studies on how regional air pollution alters nutrient cycling, growth efficiency and carbon allocation, species diversity and seedling recruitment, and genetics of tree species populations are being initiated during Fall 1987 and Spring/Summer 1988. The research studies are designed to examine the hypotheses shown in Table 9.

USING COLOR-INFRARED VIDEO IN THE GYPSY MOTH DEFOLIATION SURVEY

Frank J. Sapio (DNR)
David P. Lusch (MSU) and
Ronald L. Priest (MDA)

Defoliation was surveyed by sketch-mapping and color infrared video in 1987. Plans for acquiring the complete gypsy moth defoliation data via color infrared (CIR) video fell through due to problems with renting the camera and uncooperative weather for the week when we had the camera. Despite this setback, substantial progress was made. One half of the area was surveyed with video and several adjustments were made for the 1988 season.

Recent advancements in video technology have allowed us to assemble possibly the nation's very best and most cost-efficient system for acquiring gypsy moth defoliation data. The new Super VHS video format will allow us to almost double our image resolution and increase the clarity of the video image. We have purchased this video equipment for use in future gypsy moth defoliation surveys and for other monitoring and detection efforts.

Other accomplishments this year include: designing and manufacturing a camera mount by personnel with the DNR Forest Fire Experiment Station, modifying the DNR survey aircraft, and installing the mount. We have also determined that we can acquire an image with a two-mile swath width (we had been using a one-mile swath width) and still maintain enough image quality to discern moderate (50% to 75%) from heavy (76% to 100%) defoliation. This ability to differentiate defoliation levels should improve even more substantially when we use the new Super VHS System beginning in 1988.

Although many agencies in other states are beginning to investigate our rather "home-grown" approach to survey gypsy moth defoliation, Michigan is currently the only state to use this technology on an operational basis. Future plans for this project include:

1. Automation of the crab correction capabilities of our new mount;
2. Video digitization of the acquired video image and interface to the Geographic Information System;
3. Interface of the navigation system in the airplane with the video system; and
4. Separation of the luminance and chrominance signals from the camera's composite NTSC signal to further improve image clarity when interfaced with the new Super VHS video recorder.

FUNGAL PATHOGENS OF DEFOLIATED ASPEN

John Hart (MSU)

Studies were initiated in 1986 to determine the effects of gypsy moth defoliation on bigtooth and quaking aspen. Three areas of mixed northern hardwoods of about 20 acres each were aerially treated with *Bacillus thuringiensis* (Bt). Three similar adjacent areas were not sprayed and served as control plots. Tree diameter at breast height, percent defoliation, and condition were recorded within 150 subplots (73 bigtooth and 115 quaking aspen). In both sprayed and unsprayed areas, bigtooth aspen had significantly less defoliation than quaking aspen in 1986.

During May 1987, the same three areas that were sprayed in 1986 were again treated with Bt in 1987 and the three check areas were left unsprayed. In late June 1987, the condition of all trees was determined. The average defoliation was 2% for bigtooth aspen and 4% for quaking aspen. The unsprayed bigtooth aspen had 0% defoliation while the sprayed trees averaged 2%. On the average, unsprayed quaking aspen trees were 4% defoliated;

sprayed trees were 5% defoliated.

Quaking aspen. In 1986, 25 quaking aspen trees had 70% or less defoliation; none died in 1987. Ninety trees had 80% or more defoliation in 1986; eight trees died in 1987. Seven of the dead stems were colonized by *Armillaria* sp. and, in addition, three were infested with borers (Agrilus and Saperda). No pathogens or insects were observed in the eighth stem.

Bigtooth aspen. In 1986, 42 bigtooth aspen had 70% or less defoliation; none died on 1987. Thirty-one stems had 80% or more defoliation in 1986 two died in 1987. Both trees were infected with *Armillaria* sp., but borers were not present.

*****

Four quaking aspen were in plot 3, subplot 18, with 10, 20, 20, and 80% defoliation in 1986. Only the stem with 80% defoliation died in 1987. Similarly, five bigtooth aspen were in plot 3, subplot 10, with 10, 40, 50, 60, and 90% defoliation in 1986. Only the stem with 90% defoliation died in 1987.

Do these results indicate that aspen with heavy defoliation are more susceptible to secondary pathogens, or are weak aspen more likely to be defoliated by the gypsy moth?

1987 RESEARCH PAPERS
Forest Pest Management in Michigan

JACK PINE BUDWORM SURVEY SUMMARY: REGION I, MICHIGAN'S UPPER PENINSULA

Robert L. Heyd (DNR)

From June through August, 1987, we conducted the second successive survey of jack pine budworm activity in the Upper Peninsula. A comparison of data from the two surveys is made to look at the utility of pheromone trapping for predicting budworm population numbers. We are also studying the relationship of population numbers to resulting defoliation, growth loss, and tree mortality of jack pine. The project goal is to produce better prediction tools for managing jack pine and the jack pine budworm.

BACKGROUND

Knowledge of budworm population trends and expected damage is important in our efforts to reduce future economic losses from jack pine budworm outbreaks. Surveys of budworm defoliation from the ground and from the air are useful in comparing damage levels between stands, evaluating the effectiveness of control measures, and providing a rough idea of the expanse of an infestation.

Budworm populations are monitored in the pre-adult stages to detect building populations and predict damage levels. These surveys are costly and time consuming, and often impractical when budworm populations are very low. Monitoring the adult male population with pheromone traps may offer a desireable alternative. Pheromone trapping allows managers to monitor large areas of jack pine more efficiently, especially at low population levels. Theoretically, an effective pheromone trapping system can be used to monitor long-term fluctuations in population densities for long-range prediction of budworm outbreaks. Lead time would be provided for special operations such as establishing pre-salvage schedules and preparing marketing-utilization efforts.

METHODS

Sixteen sites were monitored with a synthetic jack pine budworm pheromone. Sites were selected from an existing network of permanent jack pine budworm impact plots.

Impact plots contained 90 trees -- 30 trees in three plots labeled "A", "B", and "C". The center of impact plot "B" in each area was used as a trap tree in the trapping plot. A trapping plot consisted of three traps in a traingular configuration. Each leg of the triangle was approximately 40 meters (two chains) long and all traps were at least 40 meters from any roads or major openings in the forest.

Traps were hung in marked trap trees 2 to 3 meters (6 to 9 feet) above the ground and, where possible, 0.7 to 1.0 meters (2 to 3 feet) away from the tree trunk to permit free air flow and not obstruct trap openings.

Forty-eight traps were placed in the field during the first week of July and retrieved during the third week of August. Trap catches were small enough to be counted in the field. Number of male moths captured was recorded by plot.

An aerial survey of all the plots was flown in mid July. Aerial photos were taken of the plot areas and average defoliation within one mile of each of the plots was noted as follows:

20%	=	light
21 to 50%	=	moderate
>50%	=	heavy

A ground survey of defoliation was made in late July. Ten trees in each of the impact plots were carefully examined with binoculars and with the unaided eye. Individual trees were ranked according to the percentage of new foliage eaten as follows:

none	=	no observable defoliation
<20%	=	light
21 to 50%	=	moderate
>50%	=	heavy

In addition to the defoliation (damage) surveys, a number of pre-adult surveys was taken in each of the trapping plots. The first was an early larval survey conducted in early June. Thirty vegetative buds (shoots) and staminate cones (flowers) were examined from five trees in each plot. The number of tips with at least one larva was recorded. Wherever possible, 15 shoots and 15 flower clusters were examined. Where staminate cones were not abundant, more shoots than flower clusters were sampled. A survey of flower abundance was also conducted at this time. The percent of branch tips with flowers was noted:

<30% w/ flowers	=	light
31 to 60% w/flowers	=	moderate
>60% w/ flowers	=	heavy

A late larval (5th and 6th instars) survey was conducted in late June. Two 15-inch branch samples were taken from the mid-crown of each of three trees in each of the three impact plots. Samples were collected in a basket attached to a pole pruner. The larvae were counted and a total for each tree was recorded. An average number of larvae per 15-inch branch was then determined.

Pupal surveys were conducted in each of the plots from mid to late July. The time to collect pupae or pupal cases from the lower branches and understory trees was recorded. If five pupae were found within five minutes of the recorded starting time, sampling stopped. If five pupae were found within five minutes, examination continued until 25 pupae were found. Collected pupae were stored to determine the emergence rate of adults and the prevalence of budworm parasites and disease pathogens.

Upon completion of the population surveys, tree condition was assessed within each plot. All trees were examined for changes in growth, defoliation ranking, and percent live crown.

RESULTS

Table 10 displays the results of the defoliation and population surveys from 1987. The average number of early instar larvae (#/15 shoots and 15 flowers), the average number of late instar larvae (#/15-inch branch), the average number of

pupae (# collected/5 minute interval), and the average number of moths captured per trap for each permanent sampling plot can be reviewed in both Table 10 and Figures 1 to 8. Staminate flower abundance is reported in Table 10.

Defoliation and population survey results for 1987 and 1986 are displayed graphically in Figures 1 to 4 and Figures 5 to 8, respectively. These figures also include adult trap catches for each plot from 1985 to 1987. Defoliation data in the figures are from ground surveys used to assess percent needle loss as light defoliation = 10%; moderate = 25%; and heavy = 50%. Variation within defoliation categories is not shown.

Tree growth and condition in the impact plots did not change noticeably from 1986 to 1987.

DISCUSSION

The collapse of jack pine budworm populations throughout the U.P. in 1986 has complicated the evaluation of the survey results. A seemingly significant 1986 trap catch in Plot 5 did not result in the expected defoliation in 1987 (Figure 2). Conversely, relatively small to moderate trap catches in Plot 1 for all three years resulted in the heaviest defoliation recorded for all of the Upper Peninsula in 1986 and 1987 (Figures 1 and 5). There appears to be little correlation between average pheromone trap catches and either pre-adult population survey data or defoliation estimates.

One could speculate that correlating adult trap catches with jack pine defoliation on a plot by plot basis is a very tricky business. Upon trapping a moth, one does not know if it is from a distant population or of local origin. If of local origin, is the

Table 10. Jack pine budworm defoliation and population survey results from 1987. [1]

Plot	Defoliation		Early Instar	Late Instar	Pupal	Adult	Staminate Flowers
	Aerial	Ground					
1	Moderate	Heavy	13.0	7.4	35.0	13.0	Moderate
2	Moderate	Moderate	12.0	6.9	46.0	50.0	Light
3	Light	Light	0.0	0.0	0.0	2.0	Light
4	Light	Light	1.3	0.2	0.0	1.0	Light
5	Light	Light	0.7	0.0	0.0	0.7	Moderate
6	Light	Light	0.7	0.3	1.0	8.0	Heavy
7	Light	Light	0.3	0.3	1.0	6.0	Moderate
8	Light	Light	1.0	0.2	1.0	13.0	Moderate
9	Light	Light	0.0	0.0	0.0	5.0	Moderate
10	Light	Light	0.4	0.0	0.0	1.0	Light
11	Light	Light	0.2	0.0	1.0	1.7	Light
12	Light	Light	0.0	0.0	1.0	2.0	Moderate
13	Light	Light	0.0	0.0	1.0	2.7	Moderate
14	Light	Light	0.1	0.2	0.0	0.0	Moderate
15	Light	Light	0.1	0.1	0.0	1.3	Moderate
16	Light	Light	1.9	1.1	0.0	2.0	Moderate

[1] See text for descriptions of units and collection techniques.

moth population that it represents on its way to another jack pine area outside the plot sampling boundary? Will a significant number migrate to significantly reduce the population density within the plot sampling boundary? Are migrating moths subject to trapping? If so, trapping results are certainly predictive only on a larger geographic scale.

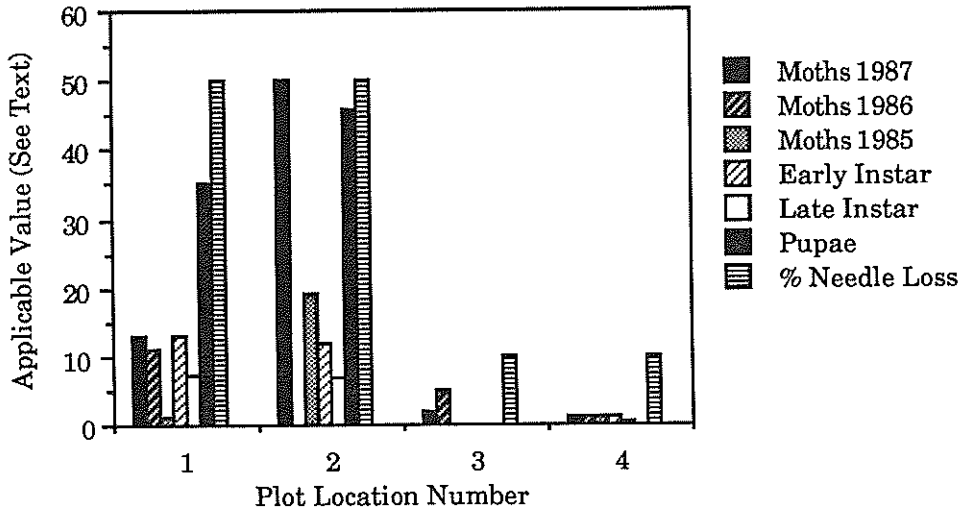


Figure 1. 1987 jack pine budworm immature stages and ground defoliation survey results with 1985 to 1987 adult pheromone trap catches for plots 1 to 4.

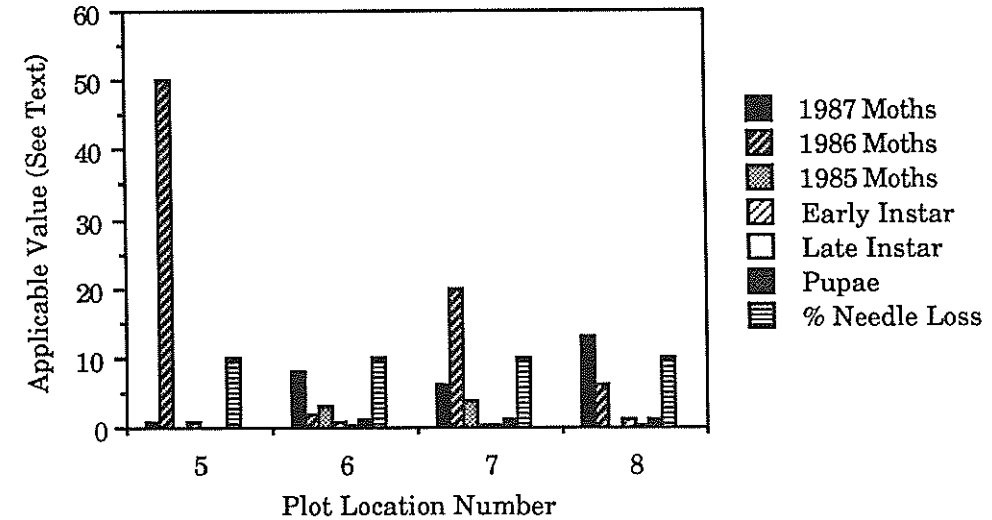


Figure 2. 1987 jack pine budworm immature stages and ground defoliation survey results with 1985 to 1987 adult pheromone trap catches for plots 5 to 8.

Jack pine flower abundance is best used to interpret the results of early larval surveys. Larval survival and vigor are positively carrelated with flower abundance. We also reported last year that heavy flowering kept larvae in the cones and away from needle feeding. This was only a temporary reprieve. These plots were heavily defoliated this year. Flower abundance does not seem to affect budworm stand selection.

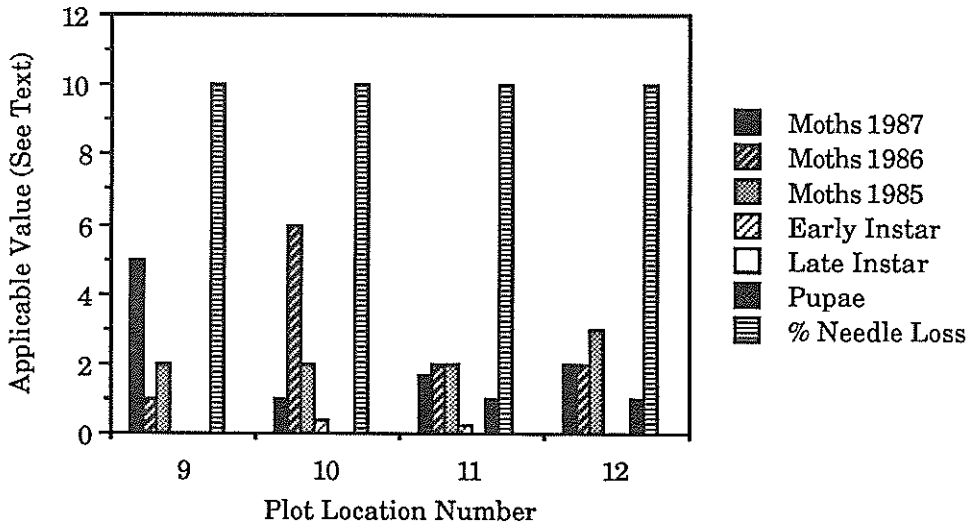


Figure 3. 1987 jack pine budworm immature stages and ground defoliation survey results with 1985 to 1987 adult pheromone trap catches for plots 9 to 12.

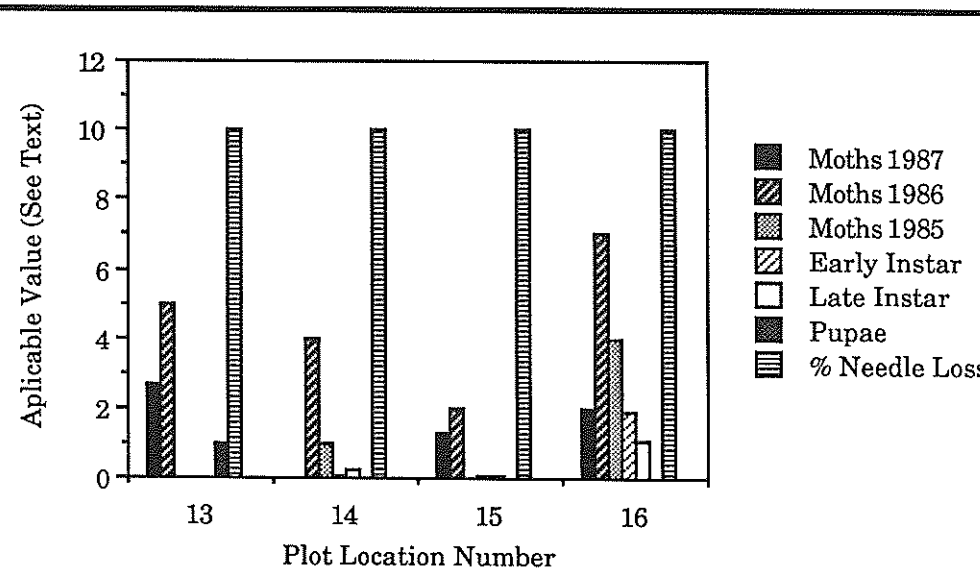


Figure 4. 1987 jack pine budworm immature stages and ground defoliation survey results with 1985 to 1987 adult pheromone trap catches for plots 13 to 16.

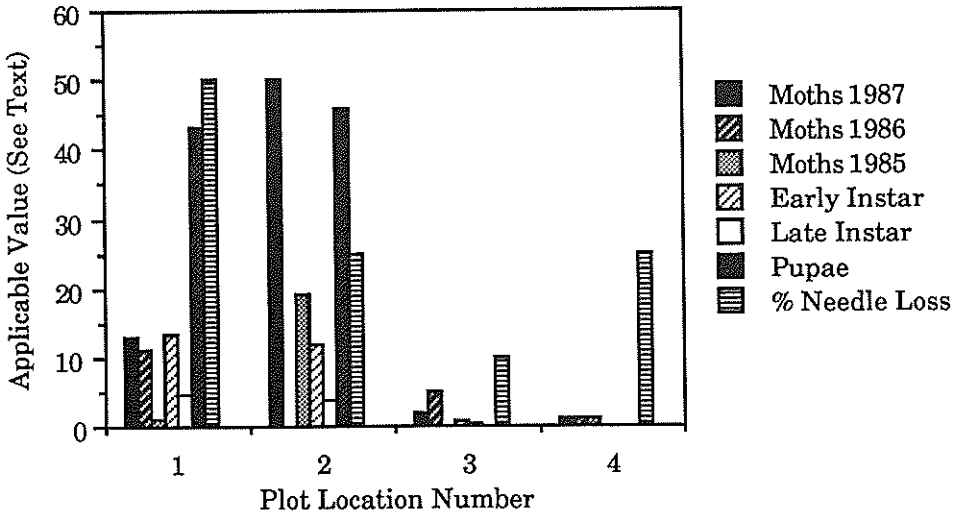


Figure 5. 1986 jack pine budworm immature stages and ground defoliation survey results with 1985 to 1987 adult pheromone trap catches for plots 1 to 4.

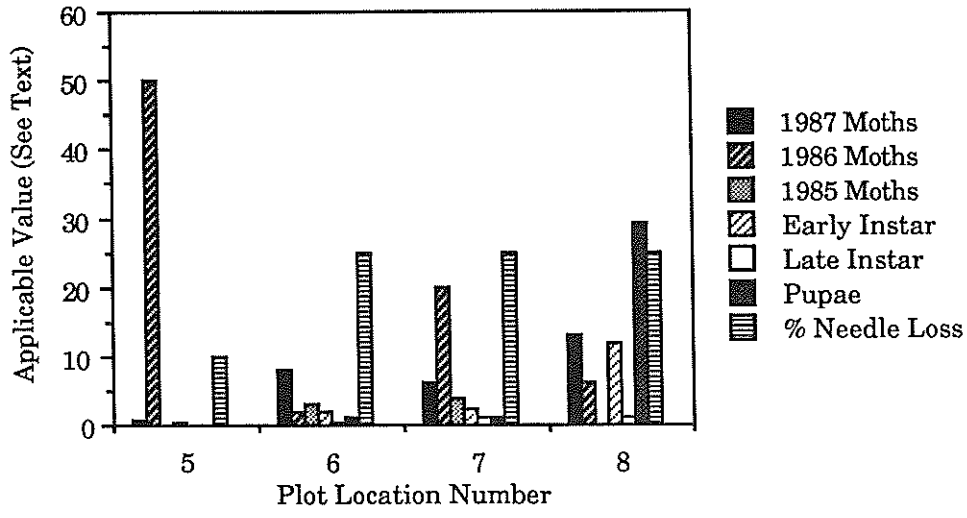


Figure 6. 1986 jack pine budworm immature stages and ground defoliation survey results with 1985 to 1987 adult pheromone trap catches for plots 5 to 8.

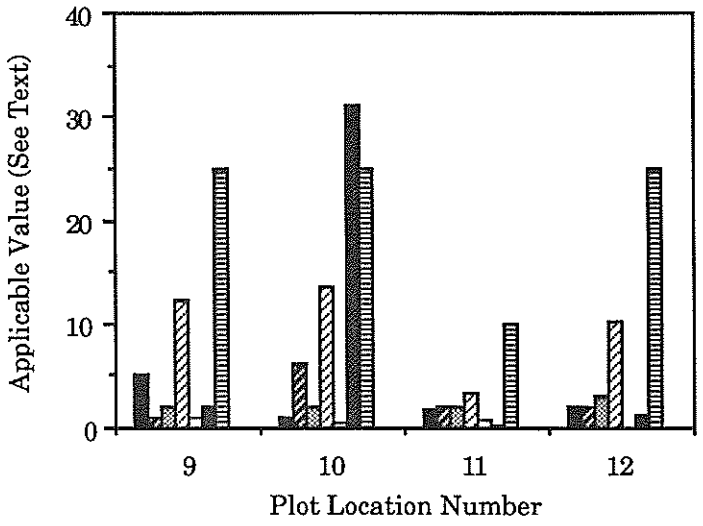


Figure 7. 1986 jack pine budworm immature stages and ground defoliation survey results with 1985 to 1987 adult pheromone trap catches for plots 9 to 12.

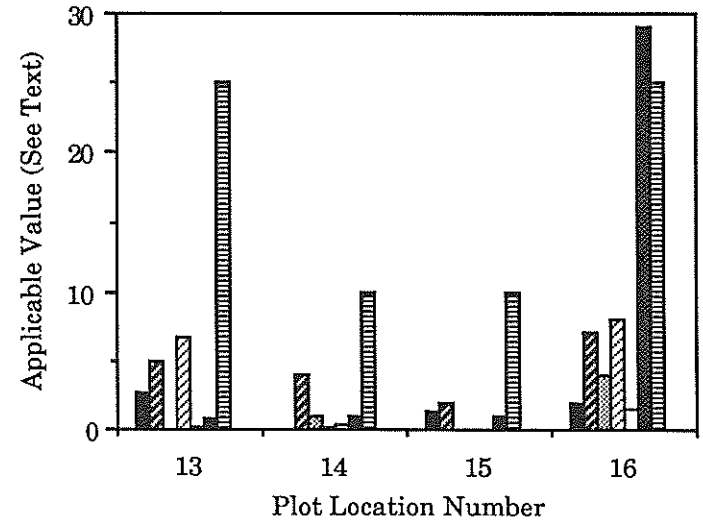


Figure 8. 1986 jack pine budworm immature stages and ground defoliation survey results with 1985 to 1987 adult pheromone trap catches for plots 13 to 16.

1987 WHITE PINE WEEVIL STUDIES

Frank J. Sapio (DNR)

The white pine weevil continues to be our most insidious pest of jack pine. Although damage varies from year to year in individual stands, we have seen an overall increase in damage throughout the region since 1984. Figure 9 shows the increase in median damage since the installation of our scouting/database system in 1984.

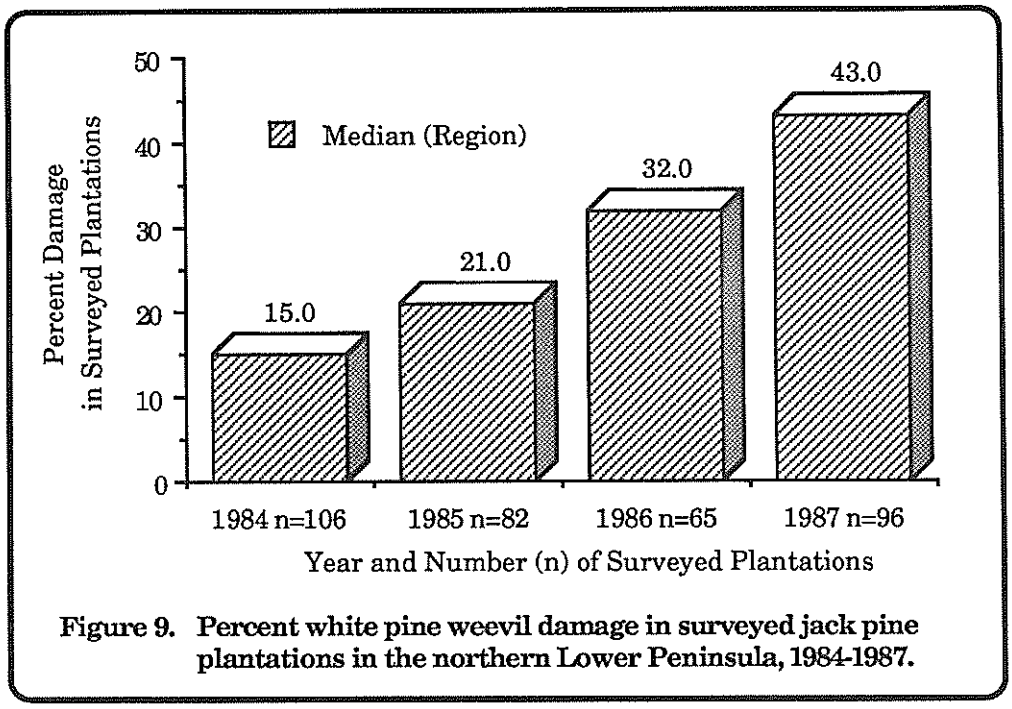


Figure 9. Percent white pine weevil damage in surveyed jack pine plantations in the northern Lower Peninsula, 1984-1987.

Alhough measuring damage in any given growing season is relatively easy, determing the impact of that damage is more difficult. In other words, we do not know how current damage will effect the growth and yield of jack pine that we plan to harvest in 50 years. This is a rather pertinent question as it is necessary to estimate the long term impact before we decide whether it is apppropriate to control the pest.

To determine the impact of the white pine weevil on the yield, volume, and form of jack pine, we installed permanent plots to measure damage and its impact on jack pine over time. Data are entered and managed on our regional pest management database. We have also installed control plots where the weevil is treated with insecticides to use as a comparison. Since this project will take time, we embarked on a rather industrious, short-term project to supplement our long-term effort.

METHODS AND MATERIALS

Jack pine stands were stratified by condition - poor, fair, and good. One stand was randomly selected from each stratum. Thirty trees were randomly selected from each stand and felled. The trees were bucked into 4 foot sections, numbered and transported indoors. Each bolt was cut up to reveal any previous weevil damage which could be related to the tree's form, defects, branchiness, DBH, volume, height and annual increment. We then examined several tree and stand variables to determine if they were related to the number of times that a tree had been weeviled. Based on this analysis, we hoped to identify: (1) how many times a tree had to be weeviled before it was culled, (2) how various tree and stand variables affect weeviling, and (3) how weeviling related to those same variables.

RESULTS

This study seemed to produce more questions than answers. Variables that we expected to correlate with weeviling did not show strong relationships. For example, previously we have used the number of exterior defects such as crook and posthorn symptoms to indicate past weeviling history of a jack pine tree. We found that this was not the case. We cannot necessarily base damage history on the external appearance of jack pine trees.

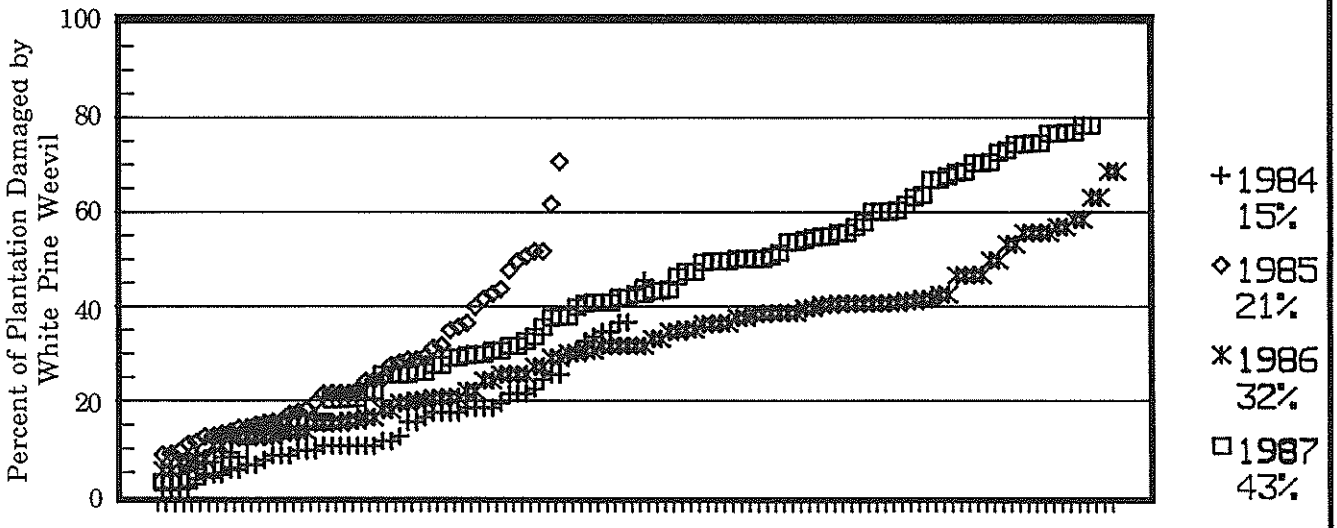
We also found inadequacies with our previous approach to predicting volume loss due to white pine wevil. The volume loss model that we had been using required us to determine how many times a jack pine trees was attacked. A major assumption of the model was that jack pine trees less than 17 feet in height will become culled if weeviled five or more times. We found that many trees in our study had been weevilied ten times or more and were still marketable. Conversely, some trees had been weeviled relatively little but were of such poor form and branchiness that they were largely unmarketable.

CONCLUSIONS

White pine weevil damage in the DNR's Region II seems to be increasing at an alarming rate (Figure 10). However, it appears that factors other than the rate of white pine weevil attack are far more critical to the ultimate growth, form, and yield of jack pine. Casual observation of our data indicates that genetics, stocking, and site may possibly have a much greater affect on the volume and form of jack pine than the white pine weevil.

Past measures that we used to estimate weevil impact are apparently invalid in large part because they were based on incorrect assumptions. We found that we were not able to accurately determine the history of weeviling from external symtoms nor was the weeviling rate closely tied with tree damage. Stem analysis appears to be a much more accurate method for estimating the weeviling history of a jack pine tree.

Although this study did not support some of our previous assumptions, it has been valuable in a number of respects. We should now be able to adjust our volume loss predictions so that they are more realistic. This study also reaffirms our opinion that management of this pest should lie not in an insect-directed tactic but in multi-faceted forest-directed tactics.



Each Symbol Represents a Surveyed Plantation (Median Rate for a Year at Right)

Figure 10. White pine weevil survey for Region II. Note significant increase in regionwide damage over the last four years.

SPORE RELEASE AND INFECTION BY *CYCLANEUSMA MINUS* NEEDLECAST DISEASE OF SCOTS PINE IN MICHIGAN

Gerard C. Adams (MSU)

This report summarizes results of a Michigan study of the periodicity of spore release by *Cyclaneusma minus*, a fungus that causes a needlecast on Scots pine. The objective is to develop an effective and economical program for protecting Scots pine from damaging levels of infections by *Cytclaneusma minus*. The study should provide biological information on the time of infection in the field. The information will be used as the basis for developing a disease control program.

This research was a cooperative effort funded in part by the United States Department of Agriculture Forest Service. The Forest Service Lead Scientist is Kathryn Robbins. Other cooperators include Jill O'Donnell, CES-MSU, Montcalm County.

THE PROBLEM

Cyclaneusma minus needlecast disease is especially destructive of Scots pine because it can infect needles of any age on the tree. In repeatedly infected trees, only one year's needles rather than three will remain on the tree at the time of harvest. Thus, the grade of the tree often is reduced or the tree may be unmarketable as a Christmas tree.

A preliminary judgment of the economic loss to a Scots pine plantation in Wisconsin surveyed by the North Central Forest Service staff, estimated a loss due to *Cyclaneusma* needlecast of 26% of the farm's potential value. Survey's conducted in Michigan during 1987 observed *C. minus* infections in plantations in most counties. If loss due to needlecast approaches 26% of the states harvest income, this economic loss may currently be as high as $13 million yearly.

Cyclaneusma minus infections of new foliage of Scots pine is symptomless. High levels of infection in nursery stock thus go undetected by the nursery operator because needle casting occurs 12 to 18 months after infection. The rapid spread of the disease throughout Michigan and neighboring states may be the consequence of the sale of one- and two-year-old (1-0 and 2-0) seedlings carrying high levels of symptomless disease. The potential for interstate transport of the disease is obvious.

Other needlecast diseases exhibit restricted periods of spore release and infection. For example, *Lophodermium seditiosum* needlecast causes infection only in the Fall. In this case, disease severity is dependent on uncommon climatic parameters such as excessive rains in September, thus applications of fungicides to cover foliage in September protects needles. Controlling the *Cyclaneusma* needlecast is a much more complex problem because spore release might occur throughout the season allowing a year-long infection period that might extend even into periods of thaw during November through March.

OBJECTIVES

a. To identify the frequency of spore discharge and its relationship to recorded daily quantities of rainfall.

b. To determine the inoculum potential of mature spores for each month from April to October.

c. To determine the monthly infection of needles by timing fungicidal applications so that foliage is protected during different months of the growing season.

FREQUENCY OF SPORE RELEASE AND RELATION TO PRECIPITATION

The relationship and frequency of spore discharge to daily quantities of rainfall was examined with spore traps. Three Burkard spore traps were situated in proximity to trees heavily infected with *Cyclaneusma* in two localities in Michigan beginning April 1, 1987. Rain gauges were up in each location. Additionally, the locations are within 2 miles and 8 miles, respectively, of accessible weather stations. Spore trap tapes were examined for numbers of spores trapped daily. Numbers of spores captured were correlated with rainfall measured to the nearest 10th of an inch in Figure 11.

RESULTS

Figure 11 represents the spore release on a daily basis from April through October 1987. Opposite the spore release is the daily quantity of rainfall. Spore trap catches demonstrate that spore release generally occurs following more than 0.01 inch of rainfall. However, it is not evident from the 1987 data whether more spores are released during warmer or cooler months or during spring, summer or fall. Spores, apparently, are discharged throughout the year during rainfall. Frequent rainfall stimulated frequent spore release.

Figure 12 shows that generally increasing amounts of rainfall appeared to cause increased spore release except in April. Perhaps fewer fungal fruiting bodies are fully mature and capable of discharging spores in April. Excessive amounts of rain such as the nearly 9 inches that occurred in August 1987 do not appear to cause the release of more spores than 2 to 3 inches of rain. This could, however, be due to the rain washing spores out of the air. Such spores would not be captured by a spore trap. Figures 11 and 12 clearly demonstrate the omnipresence of the pathogen in Michigan and emphasizes that repeated fungicide applications are needed to fully protect foliage. However, the economic benefits of repeated applications are not yet known.

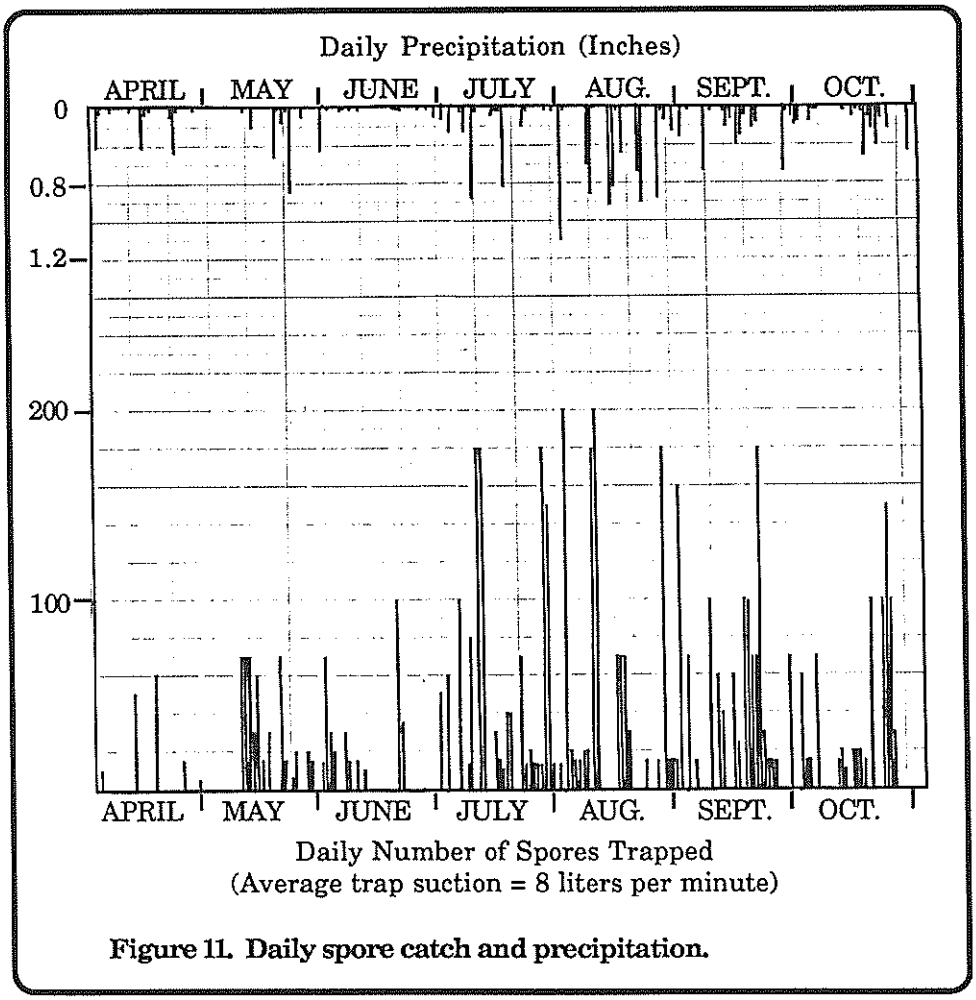


Figure 11. Daily spore catch and precipitation.

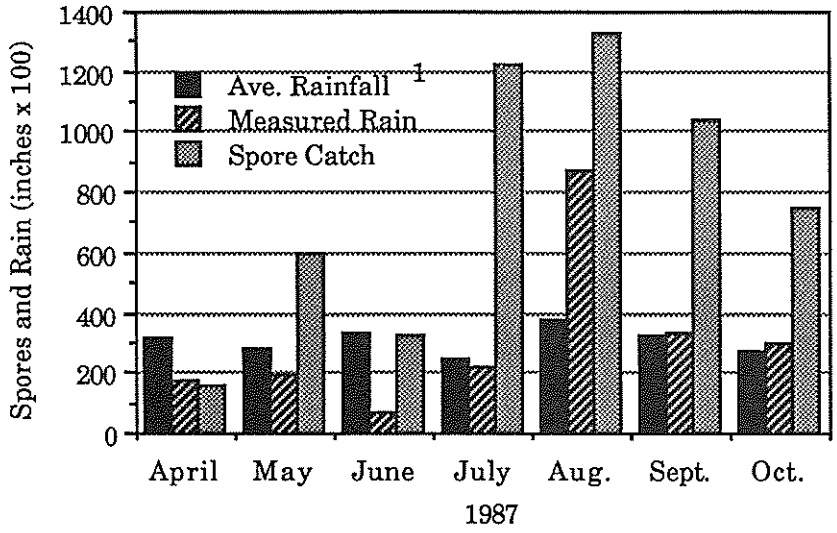


Figure 12. Monthly accumulated spore catch and precipitation.

([1] Average rain is based on 20 years of weather data.)

DETERMINING THE PERIOD OF INFECTION OF NEEDLES

A 20-acre plot was established to determine the period of infection of needles by applying an effective fungicide to protect foliage of 2 - 4 and 2 - 5 Scots pine from infection. Each treatment (24,150 sq. ft.) was compared side-by-side with an unsprayed plot and with plots treated in different months. The comparisons were replicated four times. The periods of fungicidal applications for the nine treatments are shown in Table 11.

Table 11. Periods of fungal applications for nine treatments.

Plots	Months of Foliar Application(s) of Fungicide				
1)	April				
2)	April	May			
3)	April	May	June		
4)	April	May	June	August	
5)	April	May	June	August	October
6)		May	June	August	October
7)			June	August	October
8)				August	October
9)					October
10)	no application				
11)	no application				
12)	no application				
13)	no application				

The fungicide protects for two months following one application so the period of needle protection exceeds the month of application.

Table 12. Percent needle infection after thirteen treatments.

Plots	Months of Fungicide Protection of Current Needles							% Infection	
2)	May	June						20.00	A
3)	May	June	July					7.75	B
4)	May	June	July	August				3.50	B
5)	May	June	July	August	Sept.	Oct.	Nov.	3.50	B
6)		June	July	August	Sept.	Oct.	Nov.	3.25	B
7)			July	August	Sept.	Oct.	Nov.	6.00	B
8)						Oct.	Nov.	4.75	B
1)	Unprotected (April application)							39.75	A
10)	Unprotected (no application)							23.50	A
11)	Unprotected (no application)							24.25	A
12)	Unprotected (no application)							15.00	A
13)	Unprotected (no application)							27.50	A
				Unprotected average				26.00	
				Standard deviation				9.00	

A minimum of 400 current-year's needles were collected from each replicate (1,600 for each of the nine treatments and four controls), following snow cover in November. Needles were surface sterilized with bleach and placed on laboratory media for fungal growth. The percentage of infection was determined by counting the number of needles from which the pathogen grew (Table 12).

Data on the percentage of needles infected in November show that application of fungicides after June greatly reduced the disease. However, it is not yet clear why the data do not provide more information on the percent of infection that occurred each month. This might be due to the methods used to determine the percentage of infected needles or to natural variation between the field plots. Most likely, the present methods used to isolate the fungi from the needles can not detect differences in infection more accurately than ≤ 10 percent. Further evaluations, including a visual rating, of these trials in March 1988 and 1989 and November 1988 and 1989 will follow with a repeat of the scheduled fungicide applications.

SUMMARY

a. Spores were released following almost all periods of precipitation of ≥ 0.1 inch of rain. Occassionally, spores were released even when precipitation was recorded at only trace levels. Spores were released every month with rain and usually the day's quantity of spores was correlated with the day's quantity of rain. However, in several days of July and August several releases of spores occurred successively without recorded precipitation. These releases might have been initiated by several days of dew and high humidity.

b. Spores were released each month and the quantity of spores released per month was somewhat correlated with the quantity of monthly precipitation. However, the excessive quantity of rain in August did not appear to be expressed as greater spore catches, perhaps because spores were being continuously washed out of the air. During April, spore release was less than expected for the quantity of precipitation recorded, perhaps due to the immaturity of the fungal fruiting bodies.

c. Protecting needles from infection during May and June did not reduce infections as compared to unprotected needles. This was correlated to low spore release and little rain in June. Most infection occurred following June. The test was not precise enough to determine monthly infection rates, but the fungicide was very effective in preventing infection for over two months.

LICHEN CONTROL AND MYCORRHIZA STUDIES IN PINE PLAINS REFORESTATION EFFORTS

Johann Bruhn (MTU),
Robert Heyd (DNR),
Dana Richter, and
Patricia Flemington (MTU)

BACKGROUND

We have conducted several studies over recent years with the ultimate goal of developing technology which will permit successful reforestation of sandy, burned-over, former pine plains. This work has focused on use of *Laccaria* spp. and *Scleroderma* spp. as mycorrhizal fungi for red and jack pine seedling production. Removal of lichen ground cover is being evaluated as a cost effective element of site preparation. Control of white grubs has proven to be prerequisite to the success of any field trial on these sites. Various studies have been conducted in the greenhouse, nursery, and field. Each of these is described in the following sections.

EFFECTS OF LICHEN REMOVAL WITH PRESCRIBED FIRE

The ecological influences of reindeer lichen (*Cladonia* spp.) ground cover on associated vascular plants has been the subject of considerable research and speculation (Brown and Mikola 1974, Lawrey 1986). Lichen-produced substances appear to have antimicrobial, allelopathic, and antiherbivore roles in nature. In addition, it seems clear that reindeer lichen ground cover intercepts precipitation before it can reach the soil, thus reducing the effective precipitation available for plant growth. The use of prescribed fire to destroy lichen and other ground cover may further improve plant growth through mobilization of nutrients.

Two field trials involving use of prescribed fire to remove lichen cover have been established on the Kingston Plains, near Kingston Lake in Alger County. The plantation sites are typical of much of the north-central and northeastern Upper Peninsula. Most of the area consists of deep sandy outwash plains, repeatedly burned following logging of the natural white pine and red pine cover in the early 1900's. Reindeer lichen is a major component of the ground cover over much of the area. The selected planting sites are open, flat, and carry a heavy cover of reindeer lichen.

1985 Kingston Lake Trial

The first trial was initiated in May, 1985. The primary objective of the study was to determine whether lichen removal with prescribed fire would improve red pine seedling survival. A secondary objective was to evaluate the field performance of seedlings heavily associated with the ectomycorrhizal fungus, *Thelephora terrestris*, relative to other bed-run seedlings. *T. terrestris* is a common, naturally occurring mycorrhizal fungus in nurseries and greenhouses. It has been reported to be an aggressive competitor under relatively high moisture and high nutrient conditions which occur in nurseries and greenhouses (Kenney and Woodhead 1983), and to be less helpful to loblolly pine than *Pisolithus tinctorius* (Ruehle 1980, 1981). Mead Paper Company donated planting stock from the June 1984 red pine crop grown in their Escanaba greenhouse. Seedlings strongly associated with *T. terrestris* were identified by the emanation of a brown slimy *T. terrestris* growth from the drain holes of individual styroblock cavities. Seedlings with no such evidence of *Thelephora* growth were selected as controls.

One-half of the planting site was burned as a block in the autumn of 1984 by the DNR. Lichen cover was effectively destroyed by the burn. Seedlings were planted 3 feet apart along rows 6 feet apart on May 21, 1985. Rows planted with *Thelephora*-dominated seedlings alternated with rows of control seedlings. Results of a plantation survey, on June 29, 1987, for seedling survival and growth are presented in Table 13. Survival, though unacceptable, was far greater in the burned

Table 13. Survival and growth of red pine seedlings planted on the Kingston Plains in May, 1985.

	Burned				Unburned			
	Thelephora associated		Control		*Thelephora* associated		Control	
Survival								
No. Planted	93.3a	(0.6)b	92.0	(4.0)	92.7	(1.2)	91.0	(2.6)
% Survival	19.6	(3.1)	28.1	(9.0)	4.3	(3.9)	1.9	(0.7)
Growth								
Height (cm)	18.1	(3.4)	18.5	(4.4)	16.4	(3.7)	15.6	(3.7)

a/ average for the three plantation rows
b/ standard deviation

block than in the unburned block. The high levels of overall mortality were attributed to drought and white grubs. In addition, those seedlings identified as being heavily associated with *Thelephora* at the time of planting did not survive as well as others. There did not appear to be any difference in height between surviving seedlings in different treatments.

1987 Kingston Lake Trial

The second trial was initiated in October of 1987. The primary objective was to verify the results of the 1985 study. In addition, all planting stock was treated with a micro-encapsulated Dursban® root drench for white grub control. A secondary objective was to evaluate the field performance of seedlings inoculated with one of five ectomycorrhizal fungus isolates (*Scleroderma areolatum* MTU-DLR-120, *S. macrorrhizon* MTU-DLR-108, *Laccaria bicolor* MTU-PMF-1, *L. bicolor* Sylvan Spawn Labs T813-2, and *L. laccata* MTU-DLR-5) relative to uninoculated bed-run seedlings. Mead Paper Company donated planting stock held over from the May 1986 red pine crop grown in their Escanaba greenhouse. Inoculations were conducted by MTU staff at the time of sowing using vegetative inoculum grown at MTU.

For this trial, the plantation site was divided into six blocks, with two rows of three blocks each. The central block in one row and the two end blocks in the other row were burned in September, 1987, by the DNR. Lichen cover was effectively destroyed by the burn. Seedlings were planted on October 8 and 9, 1987. From 9 to 15 rows of seedlings were planted in each block. Each row was planted with two sets of inoculated and control seedlings on a 6-foot spacing. Survival and growth will be evaluated at the end of the 1988 growing season.

FIELD, LABORATORY, GREENHOUSE, AND NURSERY OBSERVATIONS OF *SCLERODERMA* SPP. AS CANDIDATES FOR MYCORRHIZAL INOCULATION

Mycorrhizae are feeder roots modified through mutualistic infection by highly specialized parasitic fungi. Mycorrhizal feeder roots are characteristic of nearly all coniferous and deciduous tree species. Tree seedlings benefit in several ways from mycorrhizal development. Mycorrhizal seedlings are better able to access soil nutrients and are able to tolerate drought better than non-mycorrhizal seedlings (Harley and Smith 1983). Mycorrhizal seedlings are also less vulnerable to certain root diseases (Duchesne et. al. 1987).

The fungi which associate mutualistically with tree roots to form mycorrhizae differ in a number of respects, including their host species preferences and their capabilities to compete on different kinds of sites. The mycorrhizal fungi which develop naturally in nurseries

and greenhouses are not always appropriate for the intended outplanting sites (Marx and Kenney 1982). For this reason, we are attempting to introduce mycorrhizal fungi into the nursery/greenhouse which are well adapted to droughty outplanting sites.

Members of the puffball genus *Scleroderma* appear to be suitable for use in both greenhouse and nursery culture of red and jack pine in the northern Lake States. We have found *S. cepa*, *S. macrorrhizon*, and *S. polyrhizum* on sandy, xeric sites, and *S. areolatum* and *S. citrinum* on mesic to xeric sites. Red pine mycorrhizae have been synthesized in pure culture and/or greenhouse culture with *S. areolatum*, *S. cepa*, *S. citrinum*, *S. macrorrhizon*, and *S. polyrhizum* (Richter and Bruhn 1986, 1987).

Mycorrhizal puffball fungi are particularly attractive to us because their fruiting bodies (basidiocarps) constitute a mass of fungus spores enclosed in a sack-like container (the puffball). If these basidiospores can be used directly as inoculum to infect seedling roots, the expense, labor and time required to cultivate vegetative inoculum in the lab will be avoided. Nursery trials using basidiospores of *S. citrinum* and *S. macrorrhizon* to inoculate red and jack pines are underway at the Wyman Nursery in Manistique.

Nursery Seed Treatments

Routine seed treatments at the Wyman Nursery in Manistique include Thiram® as a protectant fungicide, Dow 202® latex sticker to attach the Thiram®, and powdered aluminum as a seed lubricant for smooth flow through the drill. Effects of these substances on one isolate of *S. citrinum* and two isolates of *S. macrorrhizon* were assesed in the laboratory (Flemington 1987, Flemington et al. 1987). The nursery application rate was extrapolated for each substance and incorporated into agar medium at 0, 1/2, 1, and 2 times the calculated base rate. Radial growth progress of each isolate was measured at 5-day intervals for 55 days. Using α=.05, the *S. citrinum* isolate grew fastest, and was unaffected by the aluminum treatments. The slower growing *S. macrorrhizon* isolate was inhibited by only the 2-X dose, while the faster growing *S. macrorrhizon* isolate was inhibited by all dosages. Both *S. macrorrhizon* isolates were inhibited by the 1/2-X level of Thiram®; the *S. citrinum* isolate was inhibited by the 1-X dose. All three *Scleroderma* isolates were inhibited by the 1/2-X dose of latex sticker. The *S. citrinum* isolate appears to be most compatible with nursery applications of thiram and aluminum. Elimination of Thiram® and latex sticker from nursery use might increase seedling colonization by all three *Scleroderma* isolates.

Nursery Inoculations

Scleroderma basidiocarps were collected in the summer and fall of 1985 in Michigan's Upper Peninsula and in central Wisconsin. Each collection was air-dried and placed in cold storage (-20° C). A few days prior to inoculation, basidiospores were extracted from the basidiocarp collections and separated using a 0.5 mm mesh soil sieve. Sieved basidiospores were weighed and returned to cold storage.

Two methods of inoculation with basidiospores have been performed at the Wyman Nursery: (1) inoculation of seedling beds with a water slurry of basidiospores just after sowing, and (2) inoculation of seed with dry basidiospores before sowing. For inoculation of seedling beds, 5.0 g basidiospores were suspended in 1.0 liter water with ten drops Tween-20 (a detergent to reduce surface tension). The inoculum slurry was prepared at the nursery and applied immediately by pouring uniformly along the six rows constituting 1 m of seedling bed. This resulted in a 1 m^2 test plot. One meter of bed was left untreated as a buffer between test plots. Control plots were treated with 1 liter water containing 10 drops Tween-20. One bed each of jack pine and red pine were inoculated in this fashion on May 30 and

June 3, 1986 respectively. The jack pine bed had one, four, four, and three plots inoculated with *S. areolatum*, *S. citrinum*, and two strains of *S. macrorrhizon*, respectively. The red pine bed had four plots inoculated with each of two strains of *S. citrinum* and one strain of *S. polyrhizum*.

Only red pine seed was directly inoculated with basidiospores. All seed had been previously coated with thiram fungicide according to routine nursery practice. Three seed inoculations were established on June 3, 1986: (1) 377 g dry seed were mixed with a 30 g basidiospores of *S. polyrhizum* (approximately one million spores per seed) and sown in the middle two rows for the entire length of one nursery bed; (2) 251 g dry seed mixed with 15 g basidiospores of *S. citrinum* (approximately 500,000 spores per seed) were sown in the middle two rows of most of another bed; and (3) 251 g seed slightly moistened with water and Tween-20 were mixed with 15 g spores of *S. citrinum* and sown down the middle two rows for most of a third nursery bed. Uninoculated beds served as controls.

All inoculations will be evaluated early in 1988. Seedling growth will be measured. Root systems will be examined for the white mycorrhizae characteristic of *Scleroderma* infections. Isolations will be made to verify the presence of the inoculated fungi.

IN VITRO INTERACTIONS BETWEEN MYCORRHIZOSPHERE STREPTOMYCETES AND MYCORRHIZAL FUNGI

Streptomycetes in the mycorrhizosphere exert effects upon other root-associated microflora which in turn affect plant growth (Garbaye and Bowen 1987, Strzelczyk and Pokojska-Burdziej 1984, Strzelczyk and Leniarska 1985). It may therefore be possible to inoculate conifer seedlings with ectomycorrhizal fungi and streptomycetes which interact positively to benefit plant growth.

Streptomycetes isolated from red pine mycorrhizae were either commensal or antagonistic toward selected ectomycorrhizal fungus isolates in laboratory testing (Richter et al. 1987). Streptomycete test strains were isolated from seedling mycorrhizae of red pine outplanted in cleared northern hardwood sites in Michigan's Upper Peninsula. One isolate each of *Laccaria bicolor*, *Laccaria laccata*, and *Thelephora terrestris* were selected for this study, because of (1) the frequent occurrence of these species in greenhouses, nurseries and outplanting sites, and (2) the frequent isolation of these species from red pine mycorrhizae in the study plantations. Effects were determined by comparing radial growth of fungus isolates plated adjacent to streptomycete strains on agar medium. Streptomycete strains were found which (1) favor growth of both *Laccaria* isolates but inhibit the growth of the *T. terrestris* isolate, (2) favor growth of the *L. laccata* and *T. terrestris* isolates but inhibit the *L. bicolor* isolate, (3) favor growth of the *T. terrestris* isolate but inhibit both *Laccaria* isolates, or (4) prevent growth of all three fungi.

Controlled seedling inoculation studies are planned to determine the effects of fungus/streptomycete co-inoculation on seedling growth and mycorrhiza formation.

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ARMILLARIA ROOT DISEASE IN RED PINE PLANTATIONS CONVERTED FROM HARDWOOD STANDS

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BACKGROUND

Three red pine plantation sites cleared from mixed northern hardwood stands in mid-June 1984 have been continuously monitored for *Armillaria* root disease mortality since planting was completed later that same month. Planting stock consisted of 3-0 bare root red pine seedlings provided by the USDA Forest Service Toumey Nursery in Watersmeet, Michigan. Two of the plantations are located in southern Marquette County; the third is located in southern Iron County. In early July, 1986, competing vegetation was removed mechanically using gas-powered weed-eaters equipped with brush blades. Because of the nature of other ongoing research, herbicides have not been used.

Armillaria root disease mortality among the planted red pine seedlings was first noted in 1986, the third year following stand conversion. *Armillaria* root disease is the only fatal infectious disease documented to date in the plantations. We are evaluating epidemiological factors controlling the rate of seedling mortality on these three plantations because additional mortality is certain to develop with increasing plantation age, and mortality appears to be developing at a greater rate on the Iron County site than at either of the Marquette County sites.

The causal agent of this disease is at least one member of the *Armillaria mellea sensu lato* species complex (Wargo and Shaw III 1985). These fungi cause a white rot type of decay in woody debris, stumps and moribund root systems, which are colonized by means of airborne spores and/or cord-like rhizomorphs. Rhizomorphs grow through the soil, utilizing energy from the decay of one foodbase to colonize the next. Conifer seedlings may be colonized and killed by *Armillaria* spp. following infection by rhizomorphs. Mortality increases for some period of years, as foodbase decay proceeds and seedling root systems grow to become larger targets.

Seedling vulnerability depends upon several site and biological factors. First, distribution of mortality is related to the spacing and size of hardwood stump foodbases (Pronos and Patton 1977). Seedling vulnerability increases with proximity to infested foodbases. Second, rhizomorph growth is most efficient in well-aerated light-textured soils with low rock content (Rishbeth 1978, Singh 1981). Third, seedling vulnerability is increased by the addition of any physiological stress, such as severe drought or competition.

The evaluation of *Armillaria* root disease development in the plantation plots is divided into two areas: (1) identification of the responsible pathogen species occurring at each plantation plot, and (2) evaluation of site factors and ambient conditions contributing to annual levels of disease.

SAMPLING AND DATA COLLECTION

The positions of seedlings killed by *Armillaria* root disease have been marked in the field with wooden stakes and mapped for permanent reference. As soon as seedlings develop the gray-green foliage color symptomatic of fatal decline, they are pulled up for diagnosis based on the presence of characteristic mycelial fans under the bark at the root collar. Infected seedlings are then returned to the laboratory for cultural isolation of the pathogen onto potato dextrose agar in petri dishes. *Armillaria* isolates are maintained permanently for reference.

Monitoring *Armillaria* Populations - Techniques. The genetic unit of study in populations of *Armillaria* spp. is the clone, the vegetative individual which grows and extends itself from one foodbase to the next

in the form of rhizomorphs. Clones can be distinguished in the laboratory through cultural confrontations on malt extract agar between isolates derived from dead seedlings, decaying stumps, or *Armillaria* mushrooms.

Isolates from the same clone grow together and intermingle freely, whereas isolates representing different clones form lines of demarcation where they grow into contact with one another (Kile 1986, Korhonen 1978, Mallett and Hiratsuka 1986, Siepmann 1985). *Armillaria* clones may be identified to genetically intersterile species in the laboratory by cultural confrontations on malt extract agar between (diploid) representatives of each clone and single-basidiospore isolates (haploid tester strains) representing different *Armillaria* spp. (Siepmann 1987). The normally fluffy white tester strains become dark and crusty when confronted with compatible diploid isolates of the same species.

Sorting the *Armillaria* isolates obtained from (1) dying seedlings and (2) associated decaying foodbases into clones will help to confirm or reject hardwood species foodbase preferences suggested by regression analysis. Identification of clones to species could help to explain the differences in rate of root disease development among the three plantations.

Armillaria spp. differ in pathogenicity to conifers and hardwoods (Korhonen 1978, Rishbeth 1985) to such an extent that differences in root disease observed among the plantations might be explained if the plantations are dominated by different *Armillaria* spp. For example, Rishbeth (1985) found that the host ranges of *A. mellea* isolates were more likely to encompass hardwoods as well as conifers than were the host ranges of *A. ostoyae* isolates. Though both species are considered to be highly pathogenic toward pines, Rishbeth found that his isolates of *A. mellea* were slightly more virulent toward Scots pine than were his isolates of *A. ostoyae.*

Modelling *Armillaria* Root Disease Incidence - Techniques. Because of the primary importance of stumps and their associated root systems as foodbases for *Armillaria*, it was necessary to quantify the stump populations in the plantations in order to explain the distribution of root disease on red pine seedlings. For statistical analysis, each plantation is considered a plot consisting of three replicates. Each replicate, in turn, is divided into four quarter-replicates. Right angle prisms were used to map the location of each stump or dead seedling on a Cartesian coordinate system.

Multiple regression analysis is being used to identify factors which help to explain differences in *Armillaria* root disease mortality among sites and years. Regression models are being derived which relate site and ambient conditions as independent variables to the dependent variable, seedling mortality, on each quarter-replicate. The overall significance of each tested model is evaluated using the *F* test for the associated analysis of variance. The contributions of individual independent variables in each model are evaluated using the corresponding *t* statistic.

The predictive capability of each model is indicated by its associated r^2 value. Differences among years will be evaluated by incorporating a set of classification (dummy) variables (Searle 1971) into the regression model. This produces a model identical in structure to the analysis of covariance model. The interpretation can be quite different because we are concerned with both the classification and continuous (analogous to covariates) variables, while the classical analysis of covariance model uses the covariates only to produce more homogeneous experimental material, thereby to reduce error.

PROGRESS

Table 14 presents mortality data for 1986 and 1987 on the nine plantation plot replicates. Striking differences in mortality among plots and plot replicates

Table 14. Red pine seedling mortality due to *Armillaria* root disease on each of the nine plantation plot replicates during 1986, 1987, and overall to date.

Replicate	Year	Plantation Plot: Marquette Co. 1 Number (Percent)	Marquette Co. 2 Number (Percent)	Iron Co. 1 Number (Percent)
1	1986	0 (0.00)	14 (0.82)	19 (0.87)
	1987	1 (0.04)	3 (0.18)	43 (1.98)
	Total	1 (0.04)	17 (0.99)	62 (2.85)
2	1986	4 (0.16)	2 (0.12)	17 (0.78)
	1987	4 (0.16)	5 (0.29)	36 (1.66)
	Total	8 (0.32)	7 (0.41)	53 (2.44)
3	1986	5 (0.20)	11 (0.64)	4 (0.18)
	1987	15 (0.60)	15 (0.88)	12 (0.55)
	Total	20 (0.80)	26 (1.52)	16 (0.73)

are apparent. In general, the rate of mortality increased between 1986 and 1987, especially at the Iron County site. Although the percentages of planted seedlings killed to date are still small, the plantations are only 4 years old and mortality is expected to continue to increase for at least a decade.

Monitoring *Armillaria* Populations - Progress. To date, 142 *Armillaria* isolates collected in 1986 have been sorted into 50 clones. These isolates represent 65 dead seedlings and 41, 33, 7, and 17 isolates, respectively, derived from aspen, birch, maple, and oak stumps. Clones appear to be most extensively developed at the Iron County site, where several clones extend over much of a plantation replicate. We speculate that this may reflect differences in soil texture/rockiness among the sites. Growth of rhizomorphs is probably slower, following a more tortuous path, through the rockier soils of the Marquette County sites. Alternatively, the patterns of distribution (1) of different *Armillaria* spp. or (2) of birch stumps (see Table 18, pg. 71, Model 8, and discussion below) may account for the differences in *Armillaria* clone size and aggressiveness among the three plantations. Further sorting of clones and species will proceed as time permits.

Modelling *Armillaria* Root Disease Incidence - Progress. Number of stumps and their basal areas per hectare by species are summarized for each plantation plot replicate in Tables 15 to 17. A systematic approach to regression model development has been taken (Table 18). Model 1 evaluated the relative importance of numbers of stumps and basal area as predictors of *Armillaria* root disease. For this model, the t statistic for numbers of stumps was 1.927 (P=.063) and the t statistic for basal area was 0.770 (P=.447). Though neither variable was significant in this model, attention was focused on numbers rather than basal area of stumps for subsequent model development. When the total number of stumps was entered as the sole independent variable (Model 2), the model was significant (P=.021). The shift from nonsignificant to significant for the number of stumps (as an independent variable) when basal area is removed as an independent variable indicates that considerable multicollinearity is present between the independent variables used to predict *Armillaria* root disease mortality. Multicollinearity is pervasive in the dataset used for the *Armillaria* root disease analysis. For a complete discussion of the causes and effects of multicollinearity, see Judge et al. (1980). Replacing total stump numbers with total numbers of non-sprouting stumps (presumed dead)

Table 15. Stump numbers and basal area (m^2) per hectare by species for plantation replicate at Marquette Co. 1.

		Plot Replicate					
		1		2		3	
Species	Variable	Mean[a]	S[b]	Mean[a]	S[b]	Mean[a]	S[b]
Aspen	No. Stumps	236.1	126.3	388.2	112.7	408.1	224.4
	Basal Area	11.7	6.3	16.2	3.3	19.1	7.5
Birch	No. Stumps	84.0	75.5	16.0	13.1	42.6	47.7
	Basal Area	4.2	4.4	1.0	1.4	2.3	2.6
Maple	No. Stumps	252.1	108.9	304.1	140.2	218.3	106.3
	Basal Area	17.5	7.1	29.8	7.1	16.2	11.1
Oak	No. Stumps	72.0	27.7	32.0	26.1	54.9	44.4
	Basal Area	21.2	12.8	8.2	6.5	16.7	13.6
Pine	No. Stumps	4.0	8.0	0.0	0.0	3.6	7.9
	Basal Area	0.5	1.1	0.0	0.0	0.1	0.1
Total	No. Stumps	648.3	178.0	740.3	226.9	727.9	357.4
	Basal Area	55.1	19.8	55.4	5.2	54.4	16.2

[a] Data are summarized over four quarter-replicates.
[b] Standard deviation.

further improved model significance (P=.009). Including the basal area as well as the number of non-sprouting stumps (Model 4) reduced overall model significance (P=.017). In this case, the *t* statistic for basal area was 1.241 (P=.223) and the *t* statistic for stump numbers was 2.490 (P=.018).

Further model development focused on differences in mortality attributable to foodbase suitability among stump species. Aspen, birch, maple, oak and pine stumps occur in various mixtures on the 36 quarter-replicates. On the basis of total stump numbers by species (Model 5), only birch stump distribution contributed significantly to explanation of root disease incidence (*t*=2.127, P=.003). Entering total number of birch stumps as the sole dependent variable (Model 6) greatly improved model significance (P=.003). Including both basal area and number of birch stumps (Model 7) decreased the significance of both the overall model (P=.007) and the variables involved. The *t* statistics for basal area and stump numbers in Model 7 were 1.040 (P=306) and 1.227 (P=.228), respectively. When both the total number of birch stumps and the total number of non-sprouting stumps were entered (Model 8), the overall model was highly significant (P=.006), but neither variable dominated. The *t* statistics for birch stump numbers and total numbers of non-sprouting stumps were 1.936 (P=.062) and 1.184 (P=.245), respectively. When only the numbers of non-sprouting stumps of each species entered, neither the overall model nor any of the species were

significant (Model 9). Including only the number of non-sprouting birch stumps (Model 10) provided a reasonably significant model. Finally, including both the numbers of sprouting and non-sprouting birch stumps (Model 11) improved significance slightly, but only the number of sprouting birch stumps achieved a significant t statistic (t=2.038, P=.050).

At this time, Model 6 is most informative. Birch stump distribution is the most useful single variable tested so far for predicting red pine seedling mortality level. One possible explanation for this focuses on the relative sprouting vigor of the hardwood species involved. Birch root systems might be expected to decline more quickly following clearcutting than those of aspen, maple, or oak, which are more vigorous sprouters than birch. As the most rapidly declining stumps on the plantation plots, birch stumps would represent the majority of the available foodbases for *Armillaria* at the present time. We expect the relationship between mortality level and birch stump distribution to change in the future as other species of stumps decline to the point of becoming important *Armillaria* foodbases.

Additional regression analysis will evaluate the relationships between seedling mortality and certain soil physical properties. Three variables, (1) percent rock content by volume, (2) bulk density of soil fraction <2 mm, and (3) percent soil (<2 mm) by volume, measured for each plantation plot replicate at 0 to 10 cm, 10 to 30 cm, and 30 to 50 cm, will be used.

Table 16. Stump numbers and basal area (m^2) per hectare by species for plantation replicate at Marquette Co. 2.

		Plot Replicate					
		1		2		3	
Species	Variable	Mean[a]	S[b]	Mean[a]	S[b]	Mean[a]	S[b]
Aspen	No. Stumps	485.4	172.3	204.7	79.6	368.4	231.9
	Basal Area	21.2	9.5	12.8	4.4	17.8	10.2
Birch	No. Stumps	169.6	81.9	64.3	35.1	46.8	66.2
	Basal Area	31.4	24.3	9.6	9.7	9.0	12.9
Maple	No. Stumps	391.8	72.4	269.0	112.2	327.5	147.9
	Basal Area	15.5	4.2	21.7	19.3	23.7	10.7
Oak	No. Stumps	29.2	11.7	11.7	13.5	35.1	44.8
	Basal Area	2.5	3.4	1.8	2.6	3.7	6.0
Pine	No. Stumps	11.7	13.5	35.1	30.2	0.0	0.0
	Basal Area	1.7	1.5	5.3	5.2	0.0	0.0
Total	No. Stumps	1087.7	211.4	584.8	195.7	777.8	310.5
	Basal Area	71.7	11.6	68.5	17.9	54.2	7.9

[a] Data are summarized over four quarter-replicates.

[b] Standard deviation.

Table 17. Stump numbers and basal area (m^2) per hectare by species for plantation replicate at Iron Co. 1.

		Plot Replicate					
		1		2		3	
Species	Variable	Mean[a]	S[b]	Mean[a]	S[b]	Mean[a]	S[b]
Aspen	No. Stumps	138.1	102.5	138.1	95.7	161.1	140.5
	Basal Area	6.3	4.5	5.0	2.0	7.6	6.7
Birch	No. Stumps	354.3	112.9	308.3	88.1	308.3	86.8
	Basal Area	24.8	9.9	29.2	18.6	30.1	14.3
Maple	No. Stumps	193.3	53.1	225.5	37.9	202.5	83.7
	Basal Area	7.1	4.6	5.8	2.3	5.6	2.5
Oak	No. Stumps	220.9	58.2	382.0	201.9	266.9	74.4
	Basal Area	20.4	8.5	30.3	11.5	20.3	7.1
Pine	No. Stumps	4.6	9.2	0.0	0.0	0.0	0.0
	Basal Area	0.8	1.6	0.0	0.0	0.0	0.0
Total	No. Stumps	911.2	207.4	1053.8	123.4	938.8	123.0
	Basal Area	59.4	9.6	70.2	10.0	63.6	15.0

[a] Data are summarized over four quarter-replicates.

[b] Standard deviation.

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Table 18. Characteristics of regression models tested for explanation of Armillaria root disease mortality distribution pattern on all three plantation plots (based on 36 quarter replicate records).

Model Number	Equation[a]	R^2	F[b]	P[c]
1	Y_i = -55.096 + 0.124 TOTNO + 0.951 TOTBA	.161	3.167	.055
2	Y_i = -12.314 + 0.143 TOTNO	.146	5.810	.021
3	Y_i = 33.272 + 0.187 TOTNOD	.184	7.644	.009
4	Y_i = 9.358 + 0.170 TOTNOD + 1.290 TOTBAD	.220	4.653	.017
5	Y_i = 5.818 + 0.015 NOA + 0.293 NOB + 0.156 NOM + 0.105 NOO - 0.453 NOP	.279	2.318	.068
6	Y_i = 55.213 + 0.331 NOB	.236	10.486	.003
7	Y_i = 52.889 + 1.443 BAB + 0.200 NOB	.260	5.800	.007
8	Y_i = 31.474 + 0.243 NOB + 0.095 TOTNOD	.267	6.006	.006
9	Y_i = 88.224 - 0.0002 NODA + 0.316 NODB - 1.808 NODM + 0.346 NODO - 0.242 NODP	.196	1.460	.232
10	Y_i = 70.387 + 0.391 NODB	.146	5.806	.022
11	Y_i = 61.671 + 0.381 NOLB + 0.273 NODB	.241	5.249	.010

[a]
Y_i = number of seedlings killed per ha
TOTNO = total number of stumps per ha
TOTBA = total basal area of stumps per ha
TOTNOD = total number of non-sprouting (dead) stumps per ha
TOTBAD = total basal area non-sprouting stumps per ha
BAB = total basal area (m2/ha) of birch stumps
NOLB = number of sprouting (live) birch stumps per ha
NOA, NOB, NOM, NOO, and NOP = total numbers of aspen, birch, maple, oak, and pine stumps per ha, respectively.
NODA, NODB, NODM, NODO, and NODP = number of non-sprouting stumps per ha of aspen, birch, maple, oak, and pine, respectively.

[b] *F* statistic for the overall model

[c] Level of significance attained by the *F* statistic for the overall model.

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OAK WILT IN MENOMINEE COUNTY, MICHIGAN

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BACKGROUND

Oak wilt, caused by *Ceratocystis fagacearum* (Bretz) Hunt, was introduced into Lake Township of Menominee County, Michigan, in approximately 1950 via infested oak firewood, most likely from either Illinois or Wisconsin. It appears that few, if any, additional introductions to the area have taken place over the past 35 years, although infested firewood was unwittingly moved around within the area until 1982. Species of the highly susceptible red oak group predominate in the area.

Oak wilt appears first as a wilting of the entire treetop, which generally occurs between late June and the end of August. During dry years, infected trees may not leaf out completely in the spring. Infected trees do not recover, and red oaks usually die within a week of symptom development (Gibbs and French 1980). In oak stands, disease epicenters enlarge as oak wilt spreads to adjacent trees through root grafts.

Trees killed by the disease often produce spores on sweet-smelling pressure pads during the year after they die. Pressure pads develop between the wood surface and the inner bark of trees killed by oak wilt, pushing the bark outward and causing it to crack. The sweet odor attracks insects which may vector the disease by carrying spores to fresh wounds on healthy oaks. Any kind of fresh wound to a healthy oak during the growing season, especially during May and June, may be visited by insects carrying spores. Unfortunately, oaks are most easily wounded in the spring, when both pressure pads and insect vectors are most abundant. Fortunately, the beetles (Nitidulidae) known to vector *C. fagacearum* are not specifically attracted to oak wounds, and are even commonly referred to as picnic beetles because of their lack of dietary specialization. Pressure pads are commonly produced even after infected trees are cut to firewood length.

DISTRIBUTION AND DETECTION

The area of concern consists of approximately 10,000 acres of pure northern red oak stands lying largely within 48 contiguous sections of land in Lake and Holmes Townships of southwestern Menominee County, Michigan. The existence of 169 disease epicenters, all located in 25 of these sections, has been confirmed. The chronology of oak wilt epicenter establishment on these 25 sections of land is presented in Table 19. Over 4,140 oak trees have died of oak wilt in the area to date. Estimates of annual mortality and numbers of disease epicenters established each year are presented in Table 20.

We are certain to find additional epicenters in the next few years, (1) as systematic aerial photography is made available for detection purposes and (2) until all centers have been treated. A number of years are required to locate all of the disease epicenters established during any given year. The number of disease epicenters discovered each year since 1981 is broken down by year of epicenter origin in Table 21. Efficiency of detection improves (1) as familiarity with the landbase increases and(2) as periodic systematic aerial photography becomes available. The area was systematically photographed from the air for the first time in September, 1987, using infrared film (courtesy of the USDA Forest Service, State and Private Forestry, Forest Pest Management, St. Paul, MN). We are now quite familiar with the core of the infested area and are using the 1987 photography primarily to locate previously unknown epicenters in the outlying vicinity.

We are also aware of 11 disease epicenters just across the Menominee River, in neighboring Marinette County, Wisconsin. These epicenters became established in 1985, probably as a result of severe spring windstorms. The Michigan Department of Agriculture is investigating avenues to secure the prompt treatment of these epicenters.

Table 19. Geographic distribution of oak wilt epicenters, broken down by year of origin.

T	R	S[1]	Total	1987	1986	1985	1984	1983	1982	1981	1980	1970's	1960's	1950's
34	28	6	2			1		1						
	29	1	1			1								
		3	8	4	1	3								
		15	2	2										
		35	1				1							
35	28	13	1					1						
		18	27	2	3	6	3	1	2	1	1	7	1	
		19	14	1	1	8	1	2				1		
		24	4			2	2							
		29	5		1	2				1	1			
		31	2			1				1				
		35	1			1								
	29	7	1			1								
		1	2			1					1			
		12	3	1				1	1					
		13	11		1	3	2	1		1			2	1
		14	32	3	6	10	8	1	1		1	2		
		18	6			5		1						
		23	16	1	3	5	3		1	2	1			
		24	13		5	1	2		1	2		2		
		25	8		1	3	2	1		1				
		31	2	1	1									
		35	5			2	1	1			1			
		36	1			1								
		35	1				1	1						
Totals			169	15	23	57	25	12	6	9	6	12	3	1

[1] T = Township, R = Range, and S = Section

DISEASE SPREAD

As already mentioned, oak wilt may be spread either (1) from tree to tree through root grafts or (2) overland by insect vectors. Transmission through root grafts is a highly efficient mechanism for the enlargement of disease epicenters in pure oak stands (Rexrode and Frame 1977, Gibbs and French 1980, Menge and Kuntz 1985). Though overland spread of oak wilt is much less efficient, the frequency of successful overland spread increases with the number of dead trees producing inoculum, and this number increases with time as epicenters enlarge. The average total mortality occurring on epicenters with increasing age, and prior to control efforts, is presented in Table 22. As epicenter circumference increases, so does the number of vulnerable and dying trees potentially capable of producing inoculum for overland spread of the pathogen.

It has been estimated that more than 95 percent of the trees which die of oak wilt in Minnesota become infected via root graft spread (Juzwik 1983). Rate of disease spread through root grafts varies greatly with stand conditions. In poorly stocked stands of oak and in mixed hardwood stands with low proportions of oak, disease epicenters may be limited to individual

Table 20. Chronology of oak wilt epicenter establishment and estimates of the associated annual mortality.

Number of Cenetrs	Year of Origin	Annual Mortality 1981[a]	1982	1983	1984	1985	1986	1987	Total	Mean[b]
13	1987							27	27	2 (13)[c]
23	1986						48	53	101	4 (23)
57	1985					162	178	290	630[d]	11 (53)
25	1984				71	110	109	92	382[d]	16 (22)
11	1983			21	66	45	35	30	197	18 (11)
6	1982		18	17	32	27	8	37	139	23 (06)
9	1981	33[e]	27	40	50	26	9	27	212[d]	104 (24)[f]
6	1980	40	4	7	2	18	12	28	111[d]	
12	1970's	1105	57	140	54	104	117	127	1704[d]	
3	1960's	202	20	10	77	50	44	29	432[d]	
1	1950	101	19	22	6	28	2	27	205[d]	
Total		1481	145	257	358	570	562	767	4140	

[a] These values include trees which died before 1981.

[b] Average total mortality to date per epicenter.

[c] Number of epicenters used in calculations.

[d] These values are underestimates due to incomplete data.

[e] Data in bold-faced type are estimates due to incomplete information concerning year of mortality.

[f] This value represents epicenters established in 1981 and earlier.

Table 21. Number of epicenters found each year, broken down by year of origin.

Year of Origin	Year Discovered 1987	1986	1985	1984	1983	1982	1981	Total
1987	14							14
1986	5	18						23
1985	18	27	12					57
1984	4	6	13	2				25
1983	0	4	5	0	2			11
1982	0	0	3	1	1	1		6
1981	1	1	0	1	4	1	2	10
1980	0	0	5	0	1	0	0	6
1970	1	0	2	0	2	1	6	12
1960	0	0	1	0	0	1	1	3
1950	0	0	0	0	0	0	1	1
Unknown	2	0	0	0	0	0	0	2
Total	45	56	41	4	10	4	10	170

Table 22. Average total mortality with epicenter age, in the absence of control, for epicenters established from 1984 to the present.

Year of Origin	1st Year	2nd Year	3rd Year	4th Year
1987	2.1 (13)*			
1986	2.1 (23)	4.4 (23)		
1985	3.1 (53)	6.2 (53)	13.3 (42)	
1984	2.3 (15)	8.1 (14)	12.9 (13)	20.5 (4)

* Number of disease centers used in calculation.

trees (True and Gillespie. 1961). Nevertheless, radial spread rates as great as 25 feet per year have been reported in dense red oak forests (Gibbs et al. 1984). An upper limit of 50 feet has been suggested for the intertree distance over which disease spread through root grafts may occur (Himelick and Fox 1961, Gillespie and True 1959). In Menominee County, MI, the greatest intertree single year spread distance attributed to root graft transmission to date has been 41 feet.

CONTROL OF EPICENTER EXPANSION

A vibratory plow blade pulled by a John Deere 750 tractor has been used since 1984 to establish barriers to disease spread via root grafts. The 48 inch long blade utilized in 1984 and 1985 was replaced in 1986 with a 60 inch blade purchased by Lake township and Menominee County. The number of epicenters treated in this manner is broken down by year and blade length in Table 23.

Correct placement of plow lines is critical for efficient disease control. The objective of barrier placement is to contain the pathogen while sacrificing as few healthy trees as possible within the barrier. Since the exact belowground position of the pathogen between syptomatic and apprently healthy trees is always somewhat uncertain, the first tier of healthy-looking oaks surrounding an epicenter is generally placed within the inner plow line. Healthy trees left within the inner plow line are eventually infected and killed, requiring sanitary disposal. On the other hand, barriers may be breached (1) by root grafts deeper than the plow-slice, (2) through subsequently formed root grafts across barriers placed much more than a single year's spread from the current mortality, or (3) if the barrier is misplaced within the perimeter of infected roots. The cost of barrier reconstruction is substantial, both in direct expense and in wasteful sacrifice of additional trees.

Table 23. Chronological record of barriers to oak wilt spread across root grafts established to date with the vibratory plow.

Year	Blade Length (inches)	Contract Period (hours)	Number of Epicenters Plowed		
			First Time	Touched Up	Total
1984	48	24	13	--	13
1985	48	40	50	1	51
1986	60	50	41	18	59
1987	60	50	41	23	64
Total		164	145	42	187

Two plow lines are established in the treatment of each epicenter. The inner and outer lines are intended to enclose all healthy-looking trees with less than 95 percent and 99 percent chances, respectively, of remaining uninfected for one year. Barrier locations are determined in late July, by which time most of the year's mortality has become evident.

Barriers established to date have been very effective. Only 13 cases of disease escape (involving 33 trees) became evident in 1987. Keeping in mind that these escapes crossed plow lines which were established before our quantitative model was available (see below), at least 7 of these 13 escapes would not have occurred had lines been located using the model. In light of this fact and noting the reduced number of new epicenters established in 1987, it is clear that the increased mortality observed in 1987 was caused by the prolonged growing season and occurred largely within inner plow lines (Table 20). Prolonged summer seasons in Wisconsin and Minnesota during 1987 also resulted in a similarly extended season for mortality (Steve Munson, personal communication).

MODELLING OF OAK WILT SPREAD THROUGH ROOT GRAFTS

We have developed a mathematical model based on probit probability analysis which effectively predicts the probability of disease transmission between two trees over a one-year period of time following death of the inoculum source tree. Our model is based on the size of the diseased and healthy trees and the distance between them. In 1987, nearly all barriers were established using this model. We are attempting to further refine the model to take into account the number of oak stems per acre.

To verify that the model fits equally well over the range of the data, a data distribution table (Table 24) was established, in which the number of trees observed to have died and predicted to have died were categorized by 10 foot intervals of separating distance and by the sum of the source and target tree diameters. A goodness-of-fit chi-square statistic was calculated for our chosen equation (without soil series). The calculated chi-square statistic for this distribution of the data is 30.70, compared to the tabular chi-square value of 67.1 (49 d.f., α=.05). It appears, therefore, that the model predicts mortality well over the range of the data.

Inclusion in the model of information about the occurrence of multiple stems arising from a central root system did not contribute significantly to our ability to project the probability of disease spread (P>.40). The measure of stem diameter used for such sprout clumps was the sum of the diameters of all stems in each clump. The summed diameters apparently reflect the relative size of the root system available to transmit the pathogen.

Two major soil types, one in the Grayling series and one in the Pemene series, dominate the area. The Grayling series soil is characterized as a deep, excessively drained, sandy deposit on outwash plains and lake plains, with a solum thickness of 15 to 30 inches (National Cooperative Soil Survey 1982). The Pemene series soil is a deep, well-drained soil, consisting of a loamy sand glacial till found on ground or end moraines, with typical solum thickness between 24 and 48 inches (National Cooperative Soil Survey 1985).

Soil series as mapped was found to be highly significant (P=.005) as a classification variable when added to the model (Stanfield 1988). However, soil series is mapped with considerable imprecision when the fate of an oak wilt epicenter is at stake. Addition of soil series classification to the model resulted in approximately 20 percent shorter critical intertree distances on soils of the Pemene series. Closer barriers make good sense on soils of the Pemene series, where better fertility and greater moisture-holding capacity would likely result in more compact, less widespread root systems.

Finally, reference tables for use in the field placement of plow lines were

Table 24. Data distribution comparison between field observations and model predictions.

Distance(D) between trees (ft)	Combined DBH (Source Tree + Target Tree) (4-inch diameter classes)										
	4	8	12	16	20	24	28	32	36	40	44
00.0≤D≤10.0											
No. Observations	1	9	17	35	22	8	4	1			
No. Observed Died	1	9	15	28	21	4	3	1			
No. Predicted Died	0.4	6.5	13.8	29.7	19.5	7.3	3.8	0.9			
10.1≤D≤20.0											
No. Observations		5	26	44	53	29	6	1	2	1	
No. Observed Died		3	9	18	35	19	5	0	1	0	
No. Predicted Died		1.4	10.5	23.1	33.0	19.3	4.4	0.7	1.6	0.8	
20.1≤D≤30.0											
No. Observations		2	18	26	50	36	18	6	1		1
No. Observed Died		0	0	12	27	25	10	4	0		1
No. Predicted Died		0.3	4.4	8.8	20.8	17.4	10.0	3.3	0.7		0.7
30.1≤D≤40.0											
No. Observations		2	5	13	11	10	9	3	2	1	1
No. Observed Died		0	0	1	5	2	5	2	1	0	1
No. Predicted Died		0.1	0.6	2.6	3.2	3.5	3.7	1.4	1.1	0.5	0.6
40.1≤D≤50.0											
No. Observations			4	7	2	4	4	1			
No. Observed Died			0	0	0	0	1	0			
No. Predicted Died			0.3	0.9	0.4	1.0	1.4	0.4			
50.1≤D≤60.0											
No. Observations			2	6	3						
No. Observed Died			0	0	0						
No. Predicted Died			0.1	0.5	0.4						
60.1≤D≤70.0											
No. Observations			1	5	1						
No. Observed Died			0	0	0						
No. Predicted Died			0.1	0.3	0.1						
70.1≤D≤80.0											
No. Observations				2				1			
No. Observed Died				0				0			
No. Predicted Died				0.1				0.2			

constructed from the probit model. Interestingly, the regresion model derived from the Menominee County data indicates that the diameters of the inoculum source and target trees contribute equally to the probability of transmission. This simplifies reference tables for the worker in the field, since the only two values of concern are the summed diameters of the two trees and the distance by which they are separated. Separate reference tables are constructed for the 95 percent and 99 percent probabilities of one year survival, representing limits of the inner and outer plow lines. Sets of tables may be constructed in the future to apply on different soils and/or in stands of different stocking levels. Critical separating distances necessary for a 95 percent probability of surviving one year on a Grayling sand are presented in Table 25.

While the preliminary success obtained by including soil series in the model is informative and even encouraging, application of this relationship to disease control is risky as yet. It would be impractical to determine soil series at each epicenter in the field prior to barrier establishment, and many epicenters cannot be confidently placed within mapped units of either series. There is the reasonable possibility that any given epicenter may occur on soil which is atypical of the mapping unit within which it has been placed. Application of the Pemene relationship to an epicenter on a Grayling soil might result in disease spread across one or both plow lines, while application of the Grayling relationship to an epicenter on Pemene soil would probably sacrifice trees which could be saved.

It seems likely that other more precisely definable stand characteristics would serve better than soil series mapping units as variables in models developed specifically to aid in barrier placement. Stand stocking (number of stems per acre) is a reasonable candidate for modelling which could easily be determined on site at the time of barrier placement. We expect that the probability of interetree spread decreases with the average distance between trees, as intervening trees interfere with the grafting potential of other pairs of trees.

Table 25. Distance (ft) associated with a 95 percent probability of a target tree not contracting oak wilt in the one year period following symptom expression by the source tree, based on the sum of the source and target tree diameters and assuming Grayling soil.

Combined DBH (inches)	Distance* (feet)	Combined DBH (inches)	Distance* (feet)
2	3.9	26	50.4
4	7.8	28	54.3
6	11.6	30	58.2
8	15.5	32	62.1
10	19.4	34	66.0
12	23.3	36	69.8
14	27.2	38	73.7
16	31.0	40	77.6
18	34.9	42	81.5
20	38.8	44	85.4
22	42.7	46	89.3
24	46.6	48	93.1

* Distance from center of source tree to center of target tree.

Table 26. Total mortality occurring on all epicenters by year, number of trees condemned for sanitation purposes, and number of infested trees remaining untreated.

Period	Total mortality (all centers)	Number of Trees Removed	Total Number of Trees Potentially Producing Inoculum
1981 [a]	1481		1481
1982	145		145
1983	257		257
1984	358		358
1985	570		570
1986	562	370	192
1987	767	-- [b]	-- [b]

[a] This value includes all known mortality from 1950 through 1981.

[b] All trees capable of producing inoculum in 1988 have been marked for sanitation; the actual number treated remains to be determined.

CONTROL OF OVERLAND SPREAD

Although overland spread of oak wilt by vectors is relatively inefficient in Menominee County, the establishment of new epicenters in this way must not be ignored. Natural infection courts created by storm damage can be extremely important to overland oak wilt spread in areas such as Menominee County which are subjected periodically to severe windstorms. Most of the 57 epicenters known to have originated in 1985 (see Table 20) are directly associated with trees severely damaged during the windstorms of late May, 1985. The key element in a program to curtail overland establishment of new epicenters is the reduction of inoculum available to vectors. Beginning in 1986, we have been arranging for proper overwinter disposal of all wood over three inches in diameter from oaks likely to produce pressure pads during the next growing season. Approximately 370 trees were disposed of in this fashion during the winter of 1986/87 (Table 26).

Infested wood must either be: (1) cut and completely covered with a tarp through the following summer, (2) burned prior to May, (3) taken to an approved sawmill or chipping facility, or (4) taken to an oak-free area at least a mile from the nearest oak. These options enable us to minimize the amount of inoculum produced each year.

To minimize the need to confiscate infected trees in the future, property owners are being asked to fell all healthy trees inside the inner plow line. In this way, we hope to both reinforce the vibratory plow lines and prevent the pathogen from colonizing the trees sacrificed within the inner plow line.

SUMMARY

A comprehensive oak wilt control program including (1) establishment of effective barriers to spread across root grafts, (2) removal of trees capable of producing inoculum, and (3) felling of residual healthy trees within barriers, will neutralize treated epicenters. Improved detection and public cooperation will bring existing epicenters to attention and minimize the possibility of re-introducing oak wilt into the area.

The value of attempts to raise the level of public awareness regarding the consequences of (1) moving infested wood and (2) injuring healthy oaks during the first half of the growing season cannot be overemphasized. Although the effectiveness of public awareness efforts is difficult to evaluate, such education programs are generally quite inexpensive and become cost effective if the establishment of even one new epicenter is averted.

Table 27. Centers without 1987 mortality by year of origin and year discovered.

Year Discovered	Year of Origin									
	1986	1985	1984	1983	1982	1981	1980	1970	1960	1950
1986	12	9	1							
1985		2	4	1			3			
1984			1		1					
1983				1	1	1				
1982					1	1				
1981						2				
Total	12	11	6	2	3	4	3	0	0	0

Definite progress has been made in control of Menominee County's oak wilt problem. No new mortality occurred on 41 epicenters in 1987 (Table 27). The number of new oak wilt centers established each year has been declining since 1985 (Tables 19 and 20). This number should increase dramatically next year. Younger centers are definitely the easiest to neutralize, placing a premium on prompt detection. Vibratory plowing began in 1984 with the four foot blade. In 1986, use of the five foot blade began and mortality was marked for sanitation for the first time. Healthy trees sacrificed within inner plow lines were marked for felling in 1987 for the first time. Many property owners in Lake Township have been made painfully aware of oak wilt's destructive potential. Nevertheless, with landowner cooperation these measures should neutralize the majority of the known epicenters in the next year or two.

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